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VOLUME I

FTR450261000U

ICAM MANUFACTURING COST/DESIGN GUIDE

FINAL TECHNICAL REPORT
AIRFRAMES
USER'S MANUAL—VOLUME 1

PERIOD OF PERFORMANCE
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Richard R. Preston 22 Mar 83
RICHARD R. PRESTON, Capt., USAF
Project Technical Manager
Computer Integrated Manufacturing Br.
Manufacturing Technology Division

N G Tupper
NATHAN G. TUPPER
Chief
Computer Integrated Manufacturing Br.
Manufacturing Technology Division

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Cost Drivers	Assemblies	Forgings
Design-to-Cost	Mechanical Fastening	Test, Inspection
Airframe Design	Advanced Composites	& Evaluation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The "Manufacturing Cost/Design Guide" (MC/DG) enables airframe and electronic designers to achieve lowest cost by conducting trade-offs between manufacturing cost and other design factors. When fully developed, the MC/DG will, for example, permit airframe designers, at all levels of the design process, to quickly perform cost-trade comparisons of manufacturing processes and structural performance/cost trade-offs on airframe components and subassemblies in metallic and composite materials.

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20. (Continued)

The first program, ~~reported~~ in ~~AFML-TR-76-227,~~ developed a model of the MC/DG, the contents, cost drivers, data requirements and designer-oriented formats for conventional and some emerging manufacturing technologies, and also an implementation plan.

The second program (~~Contract~~ No. F33615-77-C-5027) consisted of four phases in which manufacturing man-hour data and designer-oriented formats were developed for "Sheet-Metal Aerospace Discrete Parts", "First-Level Mechanically Fastened Assemblies", and "Advanced Composite Fabrication". Further, structural performance/manufacturing cost trade-studies were conducted by designers in industry to demonstrate utilization of the manufacturing man-hour data developed in this program.

The data developed by the five participating aerospace companies were normalized by Battelle's Columbus Laboratories and the data plotted in designer-oriented formats. Data have been developed for base parts and discrete parts. The base part is a structural element in its simplest form and when modified with designer-influenced cost elements (DICE) such as joggles, cutouts, and heat treatment, a discrete part ready for assembly is obtained. Typical DICE analyzed for mechanically fastened assemblies are accessibility, material types, part and fastener counts, and sealing requirements. For composites, typical DICE are orientation and number of plies, overlaps, fiber mix, cutouts, and quality requirements.

The data are presented in the series of formats showing cost-driver effects (CDE) and cost-estimating data (CED) and have been evaluated in trade-offs on various fuselage panels designed in titanium, aluminum, and graphite/epoxy.

The third program (~~Contract No.~~ F33615-79-C-5102) required the development of MC/DG sections on castings, forgings, extrusions, and test, inspection and evaluation (TI&E). Furthermore, as castings, forgings, and extrusions are normally machined prior to assembly in aerospace structures, data and formats were developed for the machining of typical discrete parts manufactured utilizing these methods. TI&E was included in the MC/DG as, in the case of certain materials such as graphite/epoxy and manufacturing methods such as castings, this can be a cost-driver that needs to be included in trade-off studies comparing various manufacturing methods.

The third program also required the development of an MC/DG for electronics fabrication, assembly, and TI&E. A series of typical discrete parts such as transistors, capacitors, diodes, and hybrids were analyzed and also, typical assemblies such as printed wiring boards. Hand, semiautomatic and automatic soldering and insertion processes were also analyzed. Furthermore, the manufacturing cost to meet typical reliability requirements in electronics is also presented to the designer for the selected discrete parts.

20. (Continued)

This project is reported in a six-volume Final Technical Report as follows:

VOLUME I. User's Manual - Airframes Volume 1
Contains:
- Utilization Procedures
- Trade-Off Study Examples
- MC/DG Sections for:
  - Sheet Metal
  - Mechanically Fastened Assembly
  - Composites

VOLUME II. User's Manual - Airframes Volume 2
Contains:
- MC/DG Sections for:
  - Extrusions
  - Castings
  - Forgings

VOLUME III. User's Manual - Airframes Volume 3
Contains:
- MC/DG Test, Inspection & Evaluation Section for:
  - Sheet Metal
  - Mechanically Fastened Assemblies
  - Castings
  - Forgings
  - Machining
  - Composites

VOLUME IV. User's Manual - Electronics Volume 1
Contains:
- Design Process Descriptions
- Conceptual Design Section for:
  - New Technology
  - Number of Assemblies
  - Common Functions
  - Digital Design
  - Built-in Test
  - Part Count
  - Part Selection
    - Reliabilit
    - Package
- Detail Design Section for:
  - Mechanization
  - Processes
  - Insertion Process
  - Soldering Process

VOLUME V. Project Summary

VOLUME VI. Technology Transfer Summary and Report Contents

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FOREWORD

This Manufacturing Cost/Design Guide document covers the work performed under Air Force Contract F33615-79-C-5102 from 1 October 1979 through 1 October 1982. The contract is sponsored by the Computer Integrated Manufacturing Branch, Manufacturing Technology Division, Materials Laboratory, Air Force Wright Aeronautical Laboratories. The ICAM Project Manager is Capt. Richard R. Preston. In previous phases, the following Air Force personnel directed the program; Mr. John R. Williamson, Capt. Dan L. Shunk, and Capt. Steven R. LeClair.

The organization of the program is comprised of a coalition of seven participating companies with Battelle's Columbus Laboratories (BCL) as the prime contractor. Mr. Bryan R. Noton is the BCL Program Manager. The other participating companies of the coalition are listed below:

Airframe Company Subcontractors	Program Managers
General Dynamics Corporation, Fort Worth Division	Ben E. Kaminski Phillip M. Bunting
Grumman Aerospace Corporation	Vincent T. Padden Anthony J. Tornabe
Honeywell, Incorporated	Robert R. Remski
Lockheed-California Company	Anthony J. Pillera John F. Workman
Northrop Corporation, Aircraft Group	John R. Hendel Al P. Langlois
Rockwell International Corporation, North American Aircraft Operations	Ralph A. Anderson
Rockwell International Corporation, Avionics & Missiles Group, Collins Avionics Division	John G. Vecellio
In Critique Mode: Boeing Commercial Airplane Company	David Weiss Peter H. Bain

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Approved by: Bryan R. Noton
BRYAN R. NOTON,
MC/DG Program Manager

FTR450261000U
3 Jan 1983

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SECTION 1
INTRODUCTION

1.1 Scope

With its step-by-step approach to attaining optimum performance at minimum cost, this "Manufacturing Cost/Design Guide" (MC/DG) is a tool developed expressly for designers. The need for such a guide has long existed. It presents easy-to-use formats that provides designers with manufacturing cost data developed from industry-wide practice. It allows the user (design, manufacturing, and procurement personnel) to quickly make the trade-offs necessary to achieve lowest acquisition cost with confidence. During the design phase, designers with different levels of experience can conduct simple trade-offs between manufacturing processes for metallic and composite airframe components and assemblies. The MC/DG also establishes data at a level that complements and is conducive to computer-aided design and manufacturing systems.

The MC/DG was developed by establishing a model for its contents. Manufacturing cost drivers and data requirements were identified. Designer-oriented formats meeting specified criteria for conventional and emerging technologies were recommended. Based on this model, three MC/DG sections were developed to determine the effectiveness of the overall concepts. These concepts, focusing on sheet metal aerospace discrete parts and first-level mechanically fastened assemblies, were demonstrated and proven. The applicability of the concept to the fabrication of composites was also studied, and, while a broad data development effort was not initiated, the concept was again demonstrated and proven. However, limited data has been developed for composites and is included in the contents of these volumes. Designers from major aerospace companies used the data and formats to conduct trade-off studies of structural performance and manufacturing cost of fuselage panels in aluminum, titanium, and composites. The results provided significant measurable benefits and justified continued expansion of the guide to include sections on forgings, castings, extrusions, and test, inspection, and evaluation (TI&E) of sheet metal, composites, castings, machining, and assembly. The MC/DG includes formats providing manufacturing cost data and detailed instructions for their use.

Table 1-1 lists the functional data sections of the "MC/DG for Airframes".

TABLE 1-1.

**MC/DG VOLUME CONTENTS:
MANUFACTURING TECHNOLOGIES FOR AIRFRAMES**

I	II	III	IV	V	VI
PROCURED ITEM COSTS	MATERIAL REMOVAL COSTS	DETAIL FABRICATION COSTS	MATERIAL TREATMENT COSTS	ASSEMBLY* COSTS	TEST, INSPECTION AND EVALUATION COSTS
EXTRUSIONS CASTINGS FORGINGS	MACHINING (UNDER DEVELOPMENT)	SHEET METAL COMPOSITES	HEAT TREATMENT SURFACE TREATMENT	METALLIC ASSY. NON-METALLIC ASSY. *MAJOR AND FINAL ASSEMBLY	SHEET METAL ASSEMBLY CASTINGS FORGINGS MACHINING COMPOSITES

CATEGORIES - PROCURED ITEM COSTS, ETC.
SECTIONS - FORGINGS, ETC.
SUBSECTIONS - MACHINING, ETC.

1.2 Objectives

The Manufacturing Cost/Design Guide (MC/DG) Study was initiated to further aid in the attainment of the objectives of the Integrated Computer-Aided Manufacturing (ICAM) program.

The ICAM objectives are to:

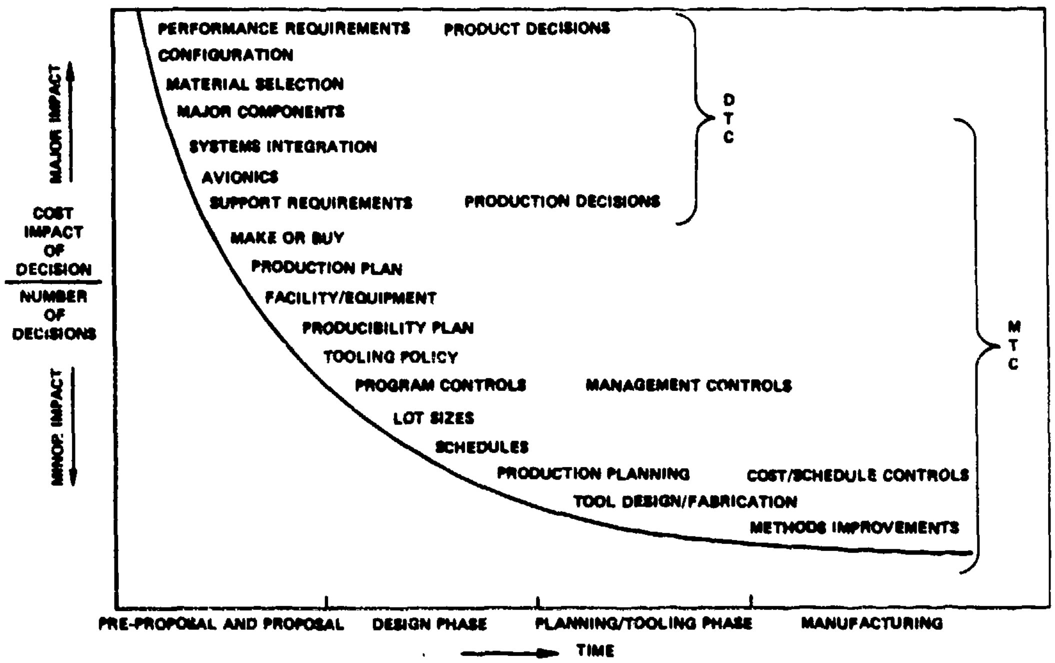
1) Reduce aerospace systems cost
2) Provide leadership to industry
3) Increase competence in Aerospace manufacturing
4) Provide for ICAM Technology Transfer
5) Improve the USAF's mobilization position
6) Demonstrate the capability for a totally integrated manufacturing system.

The Project Objectives are directed at reducing the cost of Airframes and Electronics. The specific objectives include:

1) Provide to designers urgently needed, quick, simple, and quantitative cost comparisons of manufacturing processes
2) Emphasize design orientation of MC/DG formats and manufacturing man-hour data for use at all phases of the design process, i.e., preliminary and detail design, therefore, increasing emphasis on cost as a vital design parameter
3) Enable more extensive manufacturing cost trade-offs to be conducted on airframe components and aerospace electronics fabrication and assembly
4) Emphasize potential cost advantages of emerging materials and manufacturing methods accelerating the transfer of these technologies to production hardware
5) Guide the designer to the lowest cost manufacturing process early in the design phase
6) Identify cost-driving manufacturing operational sequences, which provide targets for future computer-aided manufacturing (CAM) efforts.

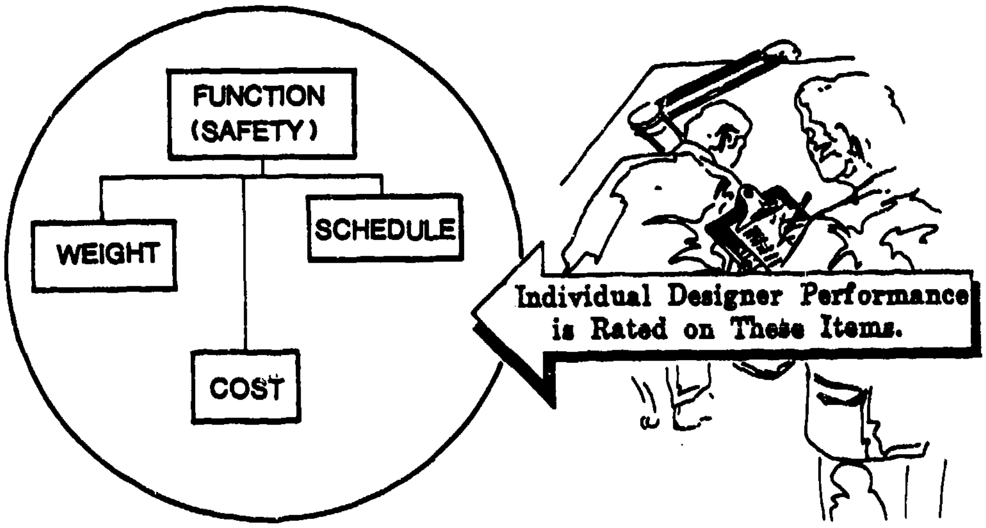
The importance or leverage to reduce cost at various stages during the airframe design process is shown in Figure 1-1. In an effort to achieve minimum cost, the performance of the designer and manufacturing engineer is often evaluated on the factors shown in Figures 1-2 to 1-4.

To provide an overview of the MC/DG sections and contents, a generalized selection aid is shown in Figure 1-5.



IMPACT OF COST VS DECISION

FIGURE 1-1



PRESENT AIRCRAFT DESIGN TEAM PRIORITIES

FIGURE 1-2

PRESENT AIRCRAFT MANUFACTURING ENGINEERING PRIORITIES

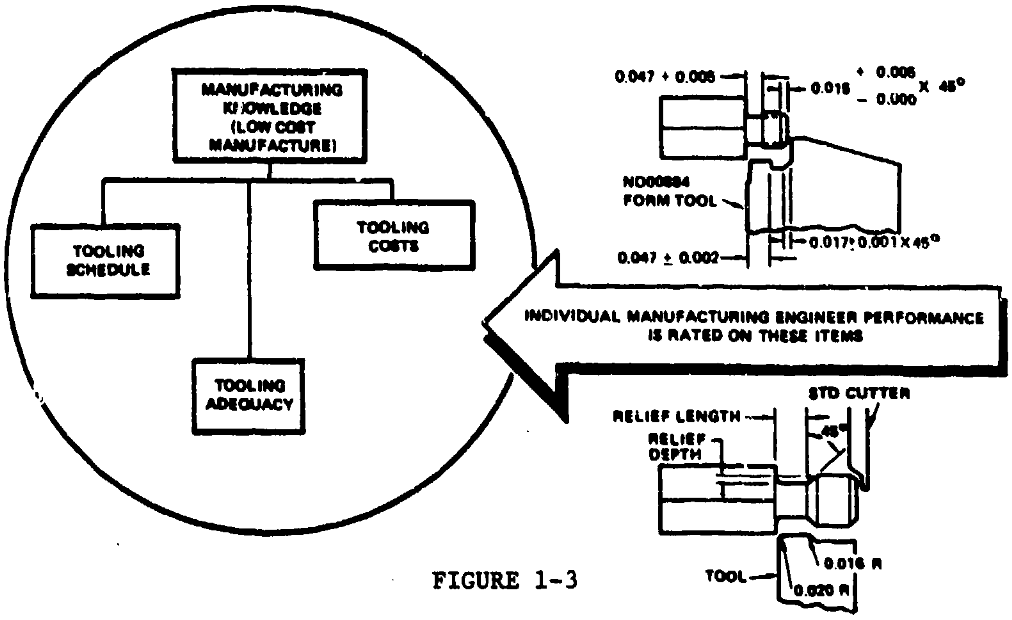


FIGURE 1-3

PRESENT AIRCRAFT MANUFACTURING TEAM PRIORITIES

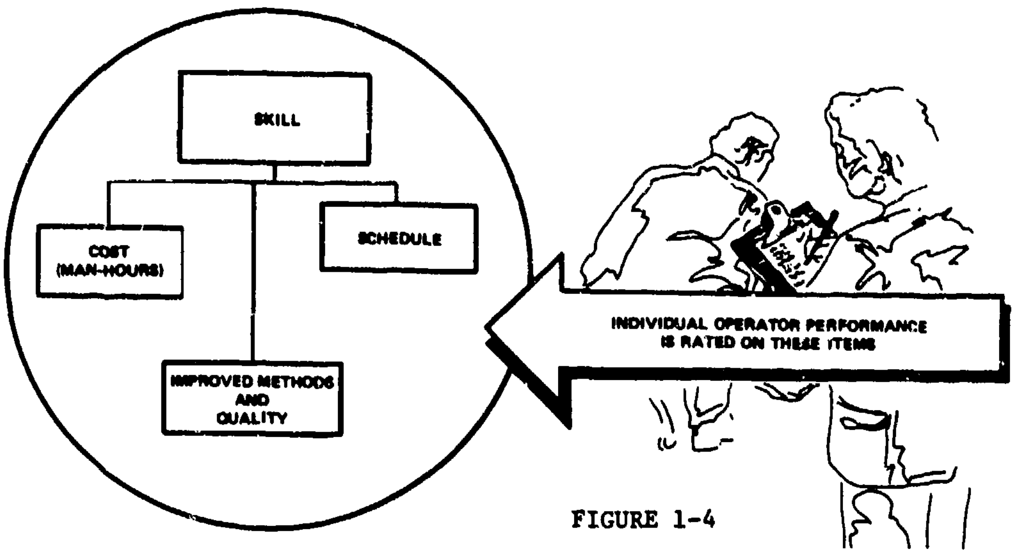


FIGURE 1-4

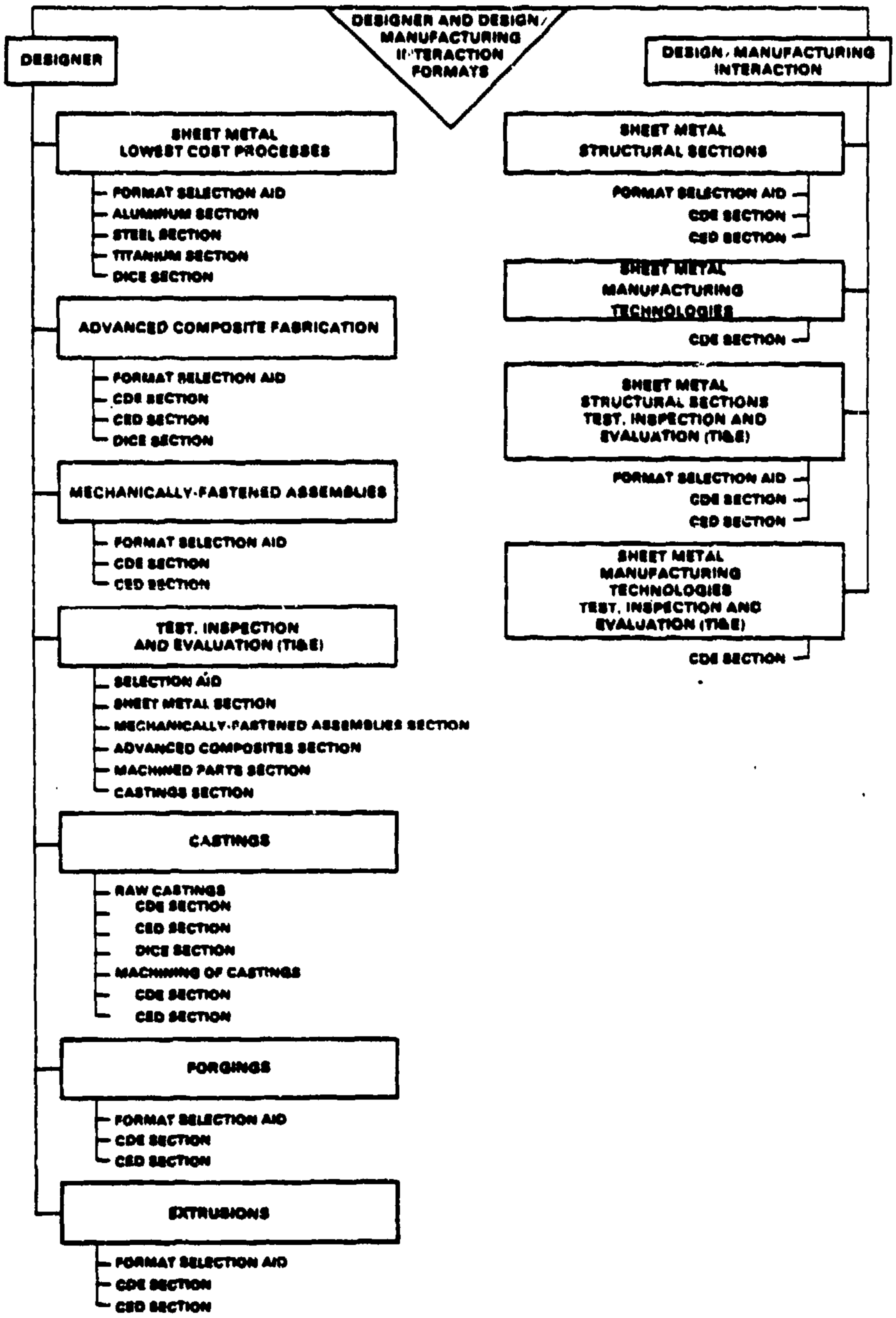


FIGURE 1-5. MC/DG SECTION SELECTION AID

1.3 Designer-Oriented Format Design Criteria

The formats and methodologies developed for the MC/DG concept (AFML-TR-76-227) were used as the basis for format development in the MC/DG for Airframes and also Electronics Fabrication and Assembly. Each project manager in industry was responsible for having the following categories of persons review the data requirements and formats:

- Management (concurrence necessary to assure MC/DG utilization, i.e., achieve technology transfer)
- Engineering (design and support)
- Manufacturing (fabrication, tooling, and quality control)
- Procurement (materials, parts, and equipment).

Furthermore, designer surveys of the MC/DG resulted in the following feedback:

- Must be simple whenever possible
- Must not be time-consuming to use in the design process
- Complicated calculations should be avoided
- Manufacturing data are urgently needed but with designer orientation
- No single airframe company can provide all manufacturing cost data required due to varying expertise
- Designers are more concerned that it is the lowest cost rather than what it costs, i.e., qualitative comparisons are important.

It was agreed that the MC/DG formats must meet the following criteria:

- Emphasize cost-drivers
- Be simple to use
- Use designer language
- Instill confidence
- Be economical
- Be accessible
- Be maintainable.

The following is a detailed explanation of the format development criteria.

1.3.1 Emphasize Cost-Drivers

The MC/DG will emphasize sensitive factors, which by minor variation in selection can cause major increases or decreases in manufacturing cost. The degree of impact on manufacturing cost during the design, developed through the selection of materials, manufacturing, and fabrication processes, must be depicted in formats and data that will make the designer readilty aware of those elements of design (cost-drivers) that pose manufacturing cost hazards.

1.3.2 Be Simple to Use

The Cost-Driver Effects (CDE) and Cost-Estimating Data (CED) formats used to guide designers will require little or no arithmetical calculations to determine the cost comparisons of design/manufacturing alternatives. The cost impact formats and graphics will provide more direct read-out of man-hours through maximum use of simple curves and tables.

1.3.3 Use Designer Language

The primary purpose of the MC/DG is to display manufacturing process capabilities and costs in a manner that will permit designers to select the most economical manufacturing approach. The formats must be developed through a close working relationship with design personnel at all the team member companies and through constructive recommendations submitted during the development of the MC/DG. The charts and terminology included with the formats must be common to the engineering community and be of the types which are recognized and employed by the designer in his daily engineering tasks.

1.3.4 Instill Confidence

The designer must have a high degree of confidence in the CDE and CED formats and manufacturing man-hour data if the MC/DG is to serve as a useful working tool for design. The formats developed will be related to practical and meaningful cost trades that are illustrative of airframe design decisions made everyday by designers. The formats must clearly provide an MC/DG for making trade-off decisions between manufacturing technologies with both comparative and quantitative cost data. It is recognized that the degree of accuracy of manufacturing man-hour data integrated into the formats will be a significant factor in determinating the confidence and degree of utilization of the MC/DG in industry.

1.3.5 Be Economical

Minimizing acquisition and maintenance costs of the data and formats takes high priority item in the development of the MC/DG.

1.3.6 Be Accessible

The MC/DG must be readily available at all designer locations. This will be handled differently within each company, but along similar lines. Copies of the MC/DG can be issued to individual designers or small engineering groups. The wider the distribution of the MC/DG to individual users, the more extensive use can be expected. The breadth and distribution should be weighted between the ease of access by individual designers and the cost of distribution. Computerization will greatly enhance the accessibility.

1.3.7 Be Maintainable

The formats must be developed to facilitate maintenance of the MC/DG. In today's highly fluid technical and economic environment, the useful life

of the MC/DG will depend upon the flexibility of the formats to accept revised or new data. One approach is through computer preparation of individual pages of loose-leaf-type volumes. The data would be stored in the central data bank and, for user accessibility, transmitted via telephone connections to remote terminals to each company for printout and multiple distribution. This is discussed in Volume III of report number AFWAL-TR-80-4115 dealing with MC/DG computerization.

1.4 Data Presentation Methodologies

Throughout the presentations of MC/DG data requirements and formats, the following two terminologies are frequently used:

COST-DRIVER EFFECTS (CDE)

COST-ESTIMATING DATA (CED).

The objectives of the CDE and CED methodologies are:

• To develop a simple approach for the use of formatted data by designers to achieve lower fabrication costs during design phases; both CDE and CED.	DIRECTION
• To provide qualitative cost guidance to perform simple trade-offs to achieve lowest fabrication cost; CDE.	COMPARISON
• To provide the designer with the capability to perform simple trade-offs to achieve quantitative rough-order-of magnitude (ROM) estimated fabrication costs; CED.	COST

The CDE and CED methodologies provide the designer with cost guidance for achieving lower manufacturing costs at the preliminary detailed design phase:

CDE achieves qualitative results

CED provides quantitative results.

The CDE approach enables preliminary and production designers to:

- Identify the intensive cost-drivers that increase the manufacturing cost of the design
- Determine the relative cost effects of cost-drivers over which they have control
- Determine pertinent cost data that allow them to perform simple trade-offs leading to comparative costs for those configurations evaluated.

The CDE approach motivates designers. They can obtain low cost designs, providing they take full advantage of the CDE data and use the lower end of the cost range wherever possible, while satisfying the performance and reliability requirements.

The CED approach provides preliminary and detail designers with the ability to perform cost-estimates through the use of simplified formats and data. CED values are both quantitative and comparative.

1.5 Data Generation

1.5.1 Recurring Costs

Throughout the MC/DG, team average production man-hours are given. Direct material costs are not included. The direct factory labor costs for manufacturing base parts and designer-influenced cost elements (DICE) were generated by the participating aerospace companies using their own time standards, excluding personal fatigue and delay (PF&D) allowances. In developing data for recurring costs for base parts and DICE, general and detailed ground rules were formulated by the coalition to assure consistent results. Elements that affect the costs, such as lot release, program quantity, and learning curves, were included in the generation of data.

Direct factory labor recurring costs consist of set-up (SU) time and run time. The SU time is that time required to prepare for a production operation. The SU time is required once for each manufacturing lot of parts.

The production run time is that time required to produce a single part from the raw stock to part completion ready for storage or use in assembly. The direct factory labor time per part is obtained by dividing the SU time by the lot size, e.g., 25, as an industry average, and then adding the run time per part.

To facilitate the use of the MC/DG, the direct factory labor and man-hours per part have been adjusted to reflect the part cost in man-hours at unit 200. To achieve this, each company has applied its own proprietary learning curves. Unit 200 base part, DICE costs, and nonrecurring tooling costs (NRTC) submitted by the team companies have been normalized by BCL and plotted on the various CDE and CED formats.

1.5.2 Nonrecurring Tooling Costs (NRTC)

Standard tools are used, when available, to fabricate the base part and to incorporate the DICE. NRTC is documented in man-hours.

As used in the MC/DG, the NRTC includes the cost of those contract tools required to make the part. Examples are forming tools, trim tools, and templates (check, drill, or router templates, etc.). The tools required to produce the tools were not included, e.g., tooling templates, tooling masters, and mock-ups. Tool material costs are included only when significant.

SECTION 2
REFERENCES

2.1 Applicable Documents

Item	Description
1	Integrated Computer Aided Manufacturing (ICAM) "Manufacturing Cost/Design Guide" (MC/DG) Interim Technical Reports for Period a. 28 September 1979 - 29 February 1980, ITR450260001U b. 28 September 1979 - 16 May 1980, ITR450260002U c. 17 May 1980 - 17 August 1980, ITR450260003U d. 18 August 1980 - 31 October 1980, ITR450260004U e. 1 November 1980 - 31 January 1981, ITR450260005U f. 2 February 1981 - 30 April 1981, ITR450260006U g. 4 May 1981 - 31 July 1981, ITR450260007U h. 3 August 1981 - 30 October 1981, ITR450260008U i. 2 November 1981 - 29 January 1982, ITR450260009U.
2	Summary of Air Force/Industry Manufacturing Cost Reduction Study, Materials Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio. Technical Report No. AFML-TM-LT-73-1, January 1973.
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5	DoD/NASA "Structural Composites Fabrication Guide", Manufacturing Technology Division, Materials Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio. Volume II, September 1982.
6	"Advanced Composites Cost Estimating Manual", Flight Dynamics Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio. Technical Report No. AFFDL-TR-76-87, August 1976.
7	Noton, B. R., et al, "Manufacturing Cost/Design Guide", Materials Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio. Technical Report AFML-TR-76-227, December 1976.

8 Noton, B. R., Claydon, C. R., Larson, M., "ICAM Manufacturing Cost/Design Guide", Materials Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio. Technical Report AFWAL-TR-80-4115, September 1977 - July 1979
a. Volume I: Demonstration Sections
b. Volume II: Appendices to Demonstration Sections
c. Volume III: Computerization.

2.2 Terms and Abbreviations

2.2.1 Glossary

Auxiliary Operations: Additional processing to the forging to obtain shapes, surface conditions, or other properties not obtainable in the regular forging operation.

Base Part: A detailed or discrete part in its simplest form, i.e., without complexities.

Base Part Cost: The standard hours to fabricate the base part projected on an improvement curve to unit 200. (The base cost is derived by applying the learning curve factor to the sum of the standard hours required for the complete fabrication of the base part.)

Beading: A forming operation in which a ridge or elongated projection is raised on sheet metal.

Bender: The portion of the dies which forms the metal so that the longitudinal axis is in two or more planes.

Bend Radius: The radius measured on the inside of a bend which corresponds to the curvature of a bent specimen or the bent area in a formed part.

Blank: The piece of sheet metal, produced in cutting dies, that is to be subjected to further press operations. A blank may have a specific shape developed to facilitate forming or to eliminate a trimming operation subsequent to forming (see Blank Development).

Blank Development: The process of determining the optimum size and shape of a blank for a specific part.

Blank Holder: That part of a forming die which holds the blank by pressure against a mating surface of the die to control metal flow and prevent wrinkling. The blank holder is sometimes referred to as "Hold Down". Pressure may be applied by mechanical means, springs, air, or fluid cushions.

Blanking: The act of cutting a blank.

Blast Cleaning: A process for removing the oxide surface, or scale, from forgings by propelling grit or shot at high velocity at the work in order to clean it.

Blocking: A forging operation which imparts to the forging its general but not exact or final shape.

Blocking Impression: The impression which gives the forging its general shape.

Blow: The impact or other pressure produced by the moving part of any forging unit.

Boss: A projection on the main body of the forging.

Box Anneal: An annealing process whereby the steel to be annealed is packed in a closed container to protect the surfaces from oxidation.

Brake Forming: A forming process in which the principal mode of deformation is bending. The equipment used for this operation is commonly referred to as a press brake.

Brake Press: A form of open frame, single action press comparatively wide between the housings, with bed designed for holding long narrow forming edges or dies. It is used for bending and forming strips and plates.

Check: A crack in a die impression, usually in a corner, generally due to forging strains localized at some relatively sharp corner.

Clean: The operation of removing the oxide coating, or scale, from the surface of the forging.

Coining: The operation of applying heavy pressure in a coining press to a surface to obtain closer tolerances or smoother surfaces. In the strict sense, the term used should be sizing.

Coining Dies: Dies in which the coining or sizing operation is performed.

Cold Shut: A forging defect caused by the meeting of metal surfaces without welding and within the die impression.

Consumed Weight: The weight of received material expended, divided by the number of forgings accepted by the customer. All scrap rejects and material loss from any cause is included.

Contract Tools: Tools that are chargeable to a specific part or contract and are unique to that contract.

Cut Off: A blanking operation in which cutting is performed along a line so that no scrap is generated.

Cut-Off Die: Sometimes called a trimming die. The cut-off die can be the last die in a set of transfer dies which cuts the part loose from the scrap, or it can be a die which cuts straight sided blanks from a coil for later use in a draw die.

Cutoffs: A pair of blades either milled in the corner of a pair of forging dies, or inserted in the dies, used to cut away a forging from the bar after the finishing blow.

Cut Weight: The weight of material necessary at the machine to fabricate one forging. This equals the net weight plus flash, sprues, tonghold, and scale loss.

Designed Tools: Tools of such a complex type that a design effort is required to ensure proper end results.

Designer-Influenced Cost Elements: Those designer-influenced cost elements (DICE) which might include joggles, holes, bends, lightening holes, and special tolerances that add cost to the base part configuration. These additional costs are due to the increased operations required over the standard manufacturing method (SMM).

Detailed or Discrete Part: The lowest form to which an airframe structure can be broken into its elemental units, i.e., base part with complexities.

Developed Blank: A flat blank with a shape that will produce a finished part with the desired configuration with a minimum of trimming operations.

Die: (a) A complete tool used in a press for any operation or series of operations such as forming, impressing, piercing, and cutting. The upper member or members are attached to the slide (or slides) of the press, and the lower member is clamped or bolted to the bed or bolster, the die members being so shaped as to cut or form the material placed between them when the press makes a stroke. (b) The female part of a complete die assembly as described in (a).

Die Clearance: The space, on each side, between punch and die.

Die Holder or Shoe: A plate upon which the die components are mounted.

Die Set: A standardized unit consisting of a die holder or lower shoe, punch holder or upper shoe, and guide pins or posts.

Die Shift: The movement of the dies from their proper place in relation to each other.

Draft: The amount of taper on the side walls of die impressions to aid the removal of the forging from the dies. Applied also to the metal on a forging caused by this taper.

Draft Angle: The taper of the draft expressed in degrees.

Drawing: Reheating after hardening to a temperature below the critical range, followed by any desired rate of cooling.

Drawing: A sheet metal deformation process in which plastic flow results in a positive strain (e_1) in one direction in the plane of the sheet surface and a negative strain (e_2) at 90° to (e_1) in the sheet surface. Drawing can only occur when sheet metal flow under the blank holder is permitted. The term drawing is sometimes loosely used to describe a wide variety of press forming operations which are actually stretch forming operations or a combination of stretching and drawing.

Drop Forging: A forging made in a drop hammer (see Forging).

Edger: The portion of the die that distributes the metal in a general proportion of the shape to be forged.

Fabrication Planning Function (Methods): The effort required to generate the SMM and complexities and additional operations required for part fabrication.

Faying Surfaces: Joining surfaces in contact, e.g., bond area of adhesively bonded joints.

Fillet: A radius imparted to inside meeting surfaces.

Fin: See Flash.

Final Yield: The quotient from dividing the net weight by the consumed weight.

Flanging: A bending operation in which a narrow strip at the edge of a sheet is bent down along a straight or curved line. It is used for edge strengthening, appearance, rigidity, and the removal of sheared edges. A flange is often used as a fastening surface.

Flash: The metal that is in excess of that required to fill out the final impression in a pair of dies and moves out as a thin plate around the parting line of the dies. Also called fin.

Flash Pan: The portion of the die which has been machined to permit the excess metal to flow through.

Forging: The product of work on plastic metal formed to a desired shape by pressure. Forgings are formed in dies in a drop hammer, forging machine, or forging press. The forging hammer imparts intermittent impact pressure, and the forging machine (upsetter) and the forging press impart squeeze pressure. While some metals, including a few steels, can be cold forged, the majority of metals are made plastic by heating for forging.

Forging Strain: A strain that has been set up in the metal by the process of forging. It may be relieved by a subsequent annealing or normalizing.

Fuller: That portion of the die used for reducing the cross section of the stock.

Gathering Stock: Any operation whereby the cross section of a portion of the stock is increased above its original size.

Grain Flow: The direction of flow lines.

Grain Size: The size of crystals in metal when measured with some standard.

Gross Weight: The weight required to produce one forging. May have the meaning of Cut Weight or Multiple Bar Weight or Consumed Weight. See those definitions.

Gutter: The portion of the die which has been relieved to provide for the excess metal after it passes through the flash pan.

Handling Holes: Holes drilled in opposite ends of the die block to permit handling by the use of a crane or bar.

Hardening: A method of increasing the hardness of a metal by controlled heating and cooling.

Hardness: Generally, the resistance of metal to deformation by mechanical force. Also refers to the hardness numbers obtained in testing for hardness by any of the several hardness tests.

Heat: Temperature of the metal, or the operation of increasing the temperature of the metal for heat treating or forging purposes.

Heat Treatment: Any operation or operations of heating metal and cooling it in order to bring out desired physical properties.

Hub: A boss which is in the center of the forging and forms a part of the body of the forging.

Impression: That portion of the dies which has been machined so as to produce the shape of the forging.

Insert: A piece of steel which is removable from a die. The insert may be used to fill a cavity, or to replace a portion of the die with a grade of steel that is better adapted for service at that particular point.

Insert Die: A small die containing the impression of a forging and which is fastened in a master block.

Inspection: The process of checking a forging for possible defects or deviations from the standards given in the specifications. Chemical inspection is the determination of the chemical analysis of the metal. Physical property inspection is the determination of the resistance of the metal to deformation against the application of force in several forms. Hardness testing is the determination of the relative hardness of the metal against a standard hardness when tested by one of several hardness tests. Cold inspection is a visual inspection of the forgings for visible defects, dimensions, weight, and surface condition. Hot inspection is a visual inspection of the forging for visible defects during the time the forgings are in the heated state.

Iron: A press operation used to obtain a more exact alignment of the various parts of a forging, or to obtain a better surface condition.

Lap: A surface defect in the forging caused by the folding of metal in a thin plate on the surface.

Layout: The transference of drawing or sketch dimensions to templates or dies for use in sinking dies. Also checking a forging or a lead cast (see below) to determine whether its dimensions are in accordance with those given in the specifications.

Lead Cast: A reproduction in lead, or a lead alloy, of the die impression, obtained by clamping the two dies together in alignment and pouring molten metal into the finished impression. Also called a lead proof.

Learning or Improvement Curve: A system for establishing unit part costs to reflect the impact of quantity.

Learning or Improvement Curve Factor: A factor applied by an individual company to determine the base-part cost at a specific unit of production.

Lock: One or more changes in the plane of the mating faces of the dies. A compound lock is one where two or more changes are in the mating faces. A counterlock is a lock placed in the dies to offset a tendency for die shift caused by a necessarily steep lock.

Lot Release: The total number of parts released for fabrication at one time.

Machine Forging: The product of the forging machine, or upsetter.

Manufacturing Equipment: Facilities used to fabricate parts, e.g., brakes, rolls, and presses.

Manufacturing Process: The operations using chemicals, heat treatment, etc., to meet required functional properties of the part such as strength and corrosion resistance.

Matched Edges: The machined surfaces of the dies at the parting plane at right angles to each other from which all measurements are determined. Sometimes called match lines or matched faces.

Methods Code: A means to identify a particular standard manufacturing method. Required complexities or additional operations to the base part will be included.

Minimum Bend Radius: That radius about which a metal can be bent without exhibiting fracture. It is often described in terms of multiples of sheet thickness.

Mismatch: The misalignment of a pair of forging dies. Also applied to the condition of the resulting forging.

Multiple Bar Weight: The cut weight plus loss in cutting as saw cut or torch burn. Crop ends from shearing may or may not be included.

Net Weight: The average shipping weight of all forgings shipped from one die sinking. Equals shape weight plus die wear and size tolerances.

Non-Designed Tools: Tools of such simple or standard configuration that no design work is required.

Non-Recurring Costs: One-time costs incurred by planning, tooling, engineering, etc.

Normalize: Heating steel to above its critical range, holding it at that temperature for the required time, and cooling it in still air.

Normalized Part Cost: The base-part cost and cost of complexities submitted to BCL by the team members are normalized or averaged by BCL for integration into the MC/DG formats.

Part Cost: Base-part cost with cost of any complexities.

Parting Line: The intersection of the surface of the impression and the parting plane. Also the flash line on a forging.

<u>Parting Plane</u>: The dividing plane between the two halves of a pair of forging dies.

<u>PF&D</u>: "Personal Fatigue and Delay". The nonproductive portion of a worker's daily labor which includes attending to personal needs, equipment failures, and other idle time.

<u>Pickling</u>: Chemical treatment to remove scale from metal.

<u>Piercing</u>: Forming a hole in sheet metal with a pointed punch with no metal slug fallout.

<u>Planish</u>: Rolling a forging, or some portion of a forging, in a pair of dies to remove the trim line or to obtain close tolerances. Generally a cold press or hammer operation, but performed at a low temperature at times.

<u>Planning Function/Methods</u>: The procedures by which the operational sequence for fabricating tooling is established.

<u>Platter</u>: The entire mass of metal upon which the hammer performs work, including the flash, sprue, tonghold, and as many forgings as are made at a time.

<u>Preforming</u>: A forming operation to prepare the sheet metal for subsequent operations.

<u>Press Forging</u>: A forging produced by a mechanical or a hydraulic press.

<u>Pressing</u>: The product or process of shallow drawing sheet or plate.

<u>Processing Equipment</u>: Facilities used to process parts by chemical treatment, heat treatment, painting, etc.

<u>Product Assurance</u>: The planned interdisciplinary and systematic establishment and application of all quality assurance, quality control, reliability and maintainability actions necessary to provide adequate confidence on an independent basis that: requirements are properly specified, that the design will achieve these requirements, that adequate tests, inspection and evaluation systems are established to detect nonconformance, and that the final product will perform the intended function(s) in the operational environment for the designed life cycle.

<u>Proof</u>: Any reproduction of a die impression in any material (see Lead Cast).

<u>Punch</u>: The operation of shearing out a slug in a forging to produce a hole.

Punch: The part of a tool that forces the metal into the die during blanking, coining, drawing, embossing, forging, powder molding or similar operations.

Punching: A process in which a hole is produced in a metal part by penetration of a punch through the metal into a fitted matching die.

Punch Press: (a) In general, any mechanical press. (b) In particular, any end-wheel, gap-frame press with a fixed bed used in piercing.

Punch Section: A section of the punch used in cutting, forming, or flanging operations which is fastened to other sections to make up the complete punch working edge.

Quality: The composite of all the attributes or characteristics including performance of an item or product.

Quality Assurance: The planned and systematic establishment of all actions (management/engineering) necessary to provide adequate confidence that nonconformance prevention provisions and reviews are established during the design phase and performed throughout the product manufacturing and life cycle phases.

Quality Control: The planned and systematic application of all actions (management/technical) necessary to control raw materials or products and detect nonconforming material or products through the use of test, inspect, evaluate, and audit techniques.

Quench Aging: A phenomenon that occurs naturally in materials following rapid cooling from an elevated temperature. The result is usually an increase in hardness and a decrease in ductility.

Realization Factors or Variance: Those factors which account for the percentage difference between standard hours and actual shop performance in the airframe industry. Realization factors represent elements, which are generally applied as multipliers to the base standard hours, to arrive at an "estimated real time" total cost to manufacture a part.

Recurring Tooling Costs: Costs incurred by planning and tool maintenance.

Restrike: Subsequently striking a forging in dies to align its several components.

Roller: A preparatory operation in a set of drop forging dies, designed to move bar forging stock into various forms of revolution so that the metal is distributed suitably for further forging in drop forging dies.

Roll Forming: A process in which coil sheet or strip metal is formed by a series of shaped rolls into the desired configuration.

Rolling Edger: An edger and a roller combined for the distribution of metal for further forging in drop forging dies.

Run Time: Base standard hours for the repetitive elements comprising the job or operation.

Sandblast: To clean forgings by propelling sand at high velocity by air pressure.

Scale: The oxide film that is formed on hot metal by chemical action of the surface metal with the oxygen in the air.

Scale Pit: A surface depression formed on the forging due to scale in the dies during the forging operation.

Setup Time: The standard hours required to make ready or to prepare for the performance of a job or operation. These hours also include teardown or cleanup efforts to return the areas and equipment to that condition necessary to undertake a different operation normally assigned to the work place or equipment.

Shank: That portion of a tool by which it is held in position during use.

Shape Weight: The weight of material contained in the geometric volume to the specified dimensions.

Shearing: A cutting operation in which the work metal is placed between a stationary lower blade and movable upper blade and severed by bringing the blades together. Cutting occurs by a combination of metal penetration and actual fracture of the metal.

Shoe: A holder required as a support for the stationary portion of trimming or forging dies.

Shotblast: Cleaning forgings to free them of scale by propelling fine steel shot at high velocity through centrifugal force on the surface of the forging.

Shrinkage: The contraction of metal when cooled.

Sink: The specialized operation of machining impressions into forging dies.

Size: The operation in a press to obtain closer tolerances on portions of a forging.

Sizing: A metal forming operation in which a formed part is more accurately shaped by restriking between an accurately fitted punch and die.

Slotting: A stamping operation in which elongated or rectangular holes are cut in a blank or part.

Soaking Heat: Holding the metal at a desired temperature sufficiently long so as to permit the metal to reach a uniform temperature.

Sprue: The portion of the die which is machined out to permit a connection between multiple impressions or between the impression and the forging bar. Sometimes called gate.

Standard Hours: The industrial engineering base standard hours (IEBSH) to perform a specific factory task, operation, or work elements. This does not refer to any specific industrial engineering methods and time measurement systems.

Standard Manufacturing Method: The factory operations and facilities used to fabricate parts to the required configuration or shape.

Standard Tools: Common shop tools that are not chargeable to a specific contract. Examples of such tools are perishable items such as drills, reamers, cutters, files, etc.; and portable equipment such as drill motors, rivet guns, squeezers; and brake and joggle dies, etc.

Straighten: Decreasing misalignment between various sections of a forging.

Strain Aging: A phenomenon that occurs in some materials following plastic deformation. In low carbon steel sheet, strain aging results in a return of discontinuous yielding, an increase in yield strength and hardness, and a decrease in ductility without substantial change in tensile strength.

Strain Hardening: An increase in hardness and strength caused by plastic deformation at temperatures lower than the recrystallization temperature. Sometimes referred to as work hardening.

Stretch Forming: A process in which a sheet section is formed over a block of the required shape while the blank is held in tension.

Support Function Modifier: Supplemental costs or man-hours, other than factory labor, added by the MC/DG industry user to the base-part cost to account for elements such as planning, quality control and assurance, manufacturing engineering, and graphics.

Support Functions: Planning, quality control and assurance, and other functions which are not hands-on effort, but are often charged as direct labor to the cost of producing the part. This depends on individual company policy.

Swage: Operation of reducing or changing the cross-sectional area of diameters by revolving the stock under fast impact blows.

Tempering: See Drawing.

Template: A gage or pattern made from a sheet and used to lay out or check dimensions on forgings or dies.

Test, Inspection, and Evaluation (TI&E): TI&E are three techniques utilized to carry out quality control activities. Specific techniques are used to determine whether materials, components, and/or end items conform to specified standards, specifications, and/or requirements. The TI&E techniques are normally addressed with specific detail in the quality control inspection plan or equivalent documents.

Tolerance: The permissible deviation from the specifications.

Tonghold: The portion of the stock by which the operator grips the stock with tongs during the forging operation.

Tool Engineering/Tool Planning Function: The effort required to establish the plan for construction of project tools.

Tool Fabrication Costs: Man-hours or costs to make a tool.

Tool Family: The tools required to fabricate a particular detailed part.

Total Tool Costs: Man-hours or costs to fabricate a tool, including materials, design, and planning costs.

Trim: To remove the flash or excess metal from a forging by a shearing operation. May be done hot or cold.

Trimmer: The dies used to remove the flash or excess stock from the forging.

Trimming Shoe: The holder used to support the trimmer.

Tumbling: A process for removing scale from forgings by impact with each other, together with jacks, sawdust, and abrasive material in a rotating container.

Type: A hardened block machined to the shape of a portion of the required forging and tapped in that part of the die impression to determine its shape.

Undercut: Sections which would lock themselves into an impression and prevent removal without distortion if driven into the impression while the metal was hot.

Underfill: The portion of a forging which does not have its true shape due to insufficient metal in the die.

Upset: Working metal so that the cross-sectional area of a portion or all of the stock is increased.

Upset Forging: A forging in which the metal has been placed in the die so that the direction of the fiber structure is at right angles to the faces of the die.

Weight: See Shape Weight, Net Weight, Gross Weight, Cut Weight, Multiple Bar Weight, Consumed Weight.

Weld: Uniting metal by the application of heat.

Yield: The quotient from dividing the net weight or the shape weight by the gross weight (see Final Yield).

SECTION 3
HOW MC/DG IS USED

3.1 Manufacturing Cost/Design Guide Design Process Interaction

It is recognized that the needs of designers at different levels, the primary users of the "Manufacturing Cost/Design Guide" (MC/DG), dictates the organization, structure, and formats of the guide sections. Therefore, a comprehensive analysis of the design process was performed in order to relate the interaction of the MC/DG with the design process.

The analysis revealed that part shape and material type would be two of the initial primary design considerations. Design factors relating to the base-part shape include loads, weight, space, and adjacent assemblies. Design factors related to the material types used for the base part include temperature, operating environment, galvanic compatibility, available space, material allowables, heat-treatment, fracture mechanics, and fatigue considerations.

The function of the MC/DG is shown in the following flow diagram, Figure 3-1, by the heavy, black-bordered boxes, while the designer functions are indicated by the broken-line blocks. The flow diagram includes the negotiable and non-negotiable design factors. The non-negotiable design factors are those over which the designer has little control, e.g., next assembly, etc., with regard to discrete-part design. The negotiable design elements may influence the manufacturing costs, e.g., joggles, lightening holes, etc. The MC/DG will assist the designer in providing the lowest-cost manufacturing process for the cost/weight and performance trade-studies.

The flow diagram depicts the relationship of the part shape and material type in the design process and follows the process through the trade study to the discrete-part selection based on lowest cost.

An analysis of the design process illustrated in the flow diagram emphasizes that the organization and formats of the MC/DG sections be structured by part shape and material type. The formats provided to the designer therefore:

(1) show cost effect of comparable shapes,
(2) show cost effect of material types, and
(3) give continuity and uniformity for each part shape in order to enable the designer to make quick comparisons, meeting the established MC/DG design criteria.

Designers will be reluctant to use MC/DG if he is required to readjust each time they change structural section or shapes.

The formats show the lowest-cost manufacturing process for each base-part shape and material. The manufacturing processes considered in the determination of the lowest-cost process are indicated on the formats.

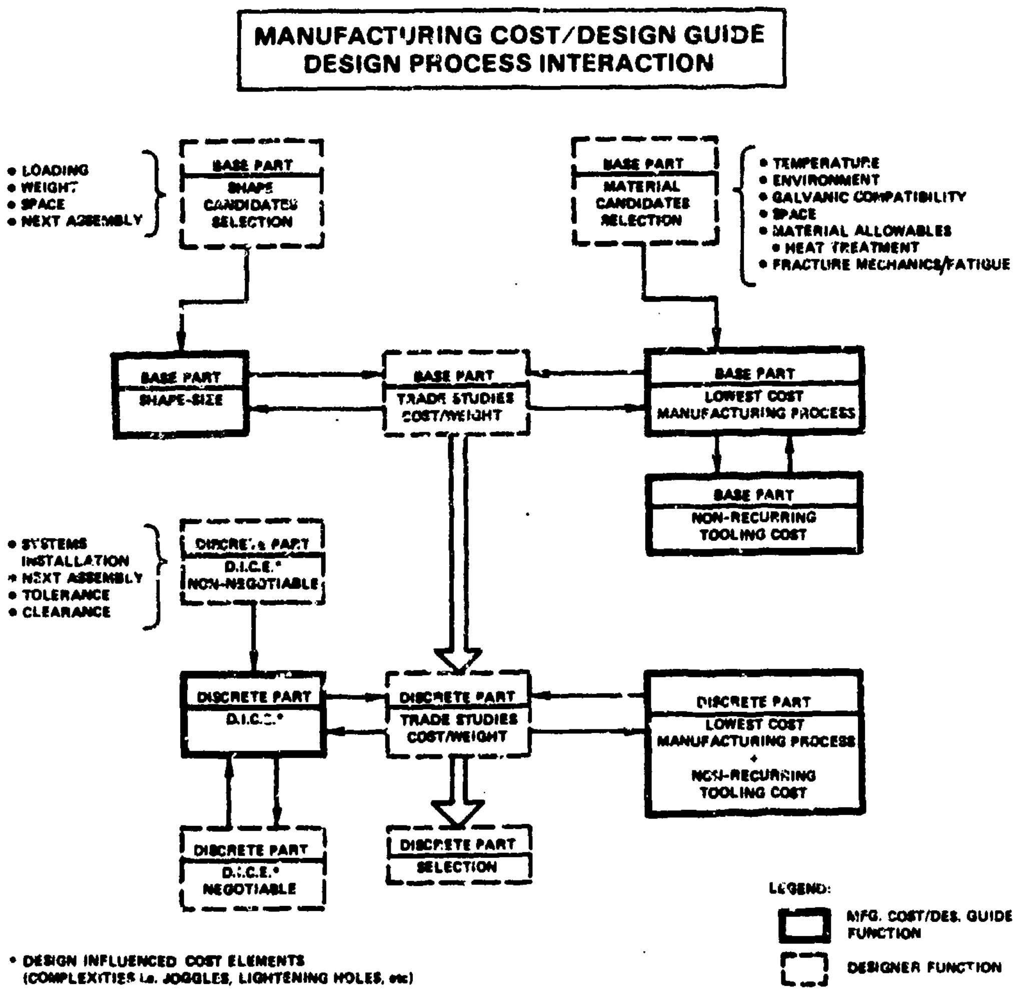


FIGURE 3-1. FLOW DIAGRAM INDICATING USE OF MC/DG

3.2 Procedure to Conduct Airframe Trade-Studies Utilizing MC/DG

The objectives of the MC/DG are to point the designer to the lowest cost structural candidate while meeting the design objectives, which may include:

- Strength and stiffness
- Minimum weight
- Satisfactory performance at elevated temperature
- Fatigue strength
- Low maintenance
- Crashworthiness
- Corrosion resistance
- Damage tolerance
- Ease of repair.

The designer uses the following procedure to conduct manufacturing cost trade-studies:

(a) Develop concepts which, in the case of a fuselage panel, will require selecting or determining the:
   - material
   - skin panel sizing
   - frame shape
   - number of frames required
   - stringer shape
   - number of stringers required
   - joining methods, e.g., bonding versus rivets
   - candidate manufacturing methods for each discrete part in the assembly

(b) Determine manufacturing costs for each panel configuration
(c) Determine assembly cost for each configuration
(d) Determine test, inspection, and evaluation (TI&E) costs
(e) Determine total manufacturing costs, which include materials and tooling
(f) Determine weight of each panel assembly
(g) Present manufacturing man-hours or costs and structural weight in summary tables and also, if appropriate, on design charts that show structural weight on the ordinate versus manufacturing cost on the abscissa.

The designer and management can then select the optimum structure (discrete part, subassembly or assembly) with respect to structural weight and other design factors and manufacturing costs. If a manufacturing facility is committed to manufacture of other components or if a facility is not available, decisions to procure parts from outside or to utilize a more costly manufacturing method can be made quickly.

The designer, having developed candidate structural configurations to meet all design requirements, such as those listed above, then utilizes the MC/DG. The following steps are typical of those taken to arrive at a lowest manufacturing cost design:

Step 1: Having selected materials that meet corrosion, elevated temperature, or other requirements, review the section ground rules for those materials, e.g., titanium sheet metal or graphite/epoxy.

Step 2: Review the ground rules of the MC/DG, to determine the discrete part and assemblies analyzed.

Step 3: Record on the designer's worksheet, the Concept No., Part No., description, labor rate, number of parts per aircraft, design quantity, and date. Use one worksheet for each part when conducting the trade-off between parts or a separate worksheet for each subassembly.

Step 4: Consult the overview selection aid of MC/DG showing various sections.

Step 5: Select sections of MC/DG representing the material types and/or joining methods, e.g., sheet metal or mechanically fastened assemblies.

Step 6: Study selection aid for each MC/DG section to be used. The selection aid will indicate the CDE formats, CED formats for the manufacturing methods, and also the test, inspection, and evaluation (TI&E) methods for the materials and parts analyzed in the MC/DG in accordance with the ground rules.

Step 7: Review CDE formats providing relative cost information for the materials, parts, and assemblies being analyzed. These CDE formats will provide qualitative information leading to the lowest cost.

Step 8: Utilize the format selection aid to determine the lowest cost manufacturing process and select the format to use. Selection aids precede the formats.

Step 9: Study CED formats for the base parts and any required Designer-Influenced Cost Elements (DICE) using the required dimensions, e.g., length for sheet metal stringers or area for panels. Note on the designer's worksheet the total labor man-hours/part (including applicable DICE) on the cost worksheet for each discrete part in the assembly.

Step 10: Check for applicable DICE. The format will indicate which DICE are applicable and in some cases DICE will be incorporated in the manufacturing methods for the base part.

Step 11: Apply the learning curve tables in the MC/DG as required. The manufacturing man-hours for each part and assembly in the MC/DG is the average value for the aerospace industry. In most cases, the average value will be sufficiently accurate for comparisons between candidate concepts meeting the design requirements. However,

when a company considers it has greater or less experience than the industry average, or if the quantity is greater or less than the 200th unit analyzed in the MC/DG in accordance with the ground rules, the learning curve tables may be required.

<u>Step 12</u>: From the CED chart selected, read the value (man-hours) for the nonrecurring tooling costs (NRTC). Note again that these values are for 200 parts or assemblies. Record the man-hours divided by 200 on the designer's worksheet.

<u>Step 13</u>: Record the current manufacturing labor rate, including direct labor fringe benefits and overhead charges, on the designer's worksheet.

<u>Step 14</u>: Using the same procedure as for manufacturing methods, determine TI&E manufacturing man-hours from that section of the MC/DG and record the TI&E recurring and nonrecurring tooling costs on the designer's worksheet.

<u>Step 15</u>: Insert materials cost based on furnished data in the company and enter material costs per part in dollars on the designer's worksheet.

<u>Step 16</u>: Consult instructions accompanying the designer's worksheet to determine aerospace vehicle program cost for the discrete part and assembly.

<u>Step 17</u>: Compare results from the designer worksheets for each part and/or subassembly and, if desired, enter on a diagram (graph) showing weight versus manufacturing cost and compare each concept. In the case of a supersonic aircraft, management and the customer may elect to sacrifice some manufacturing cost for improved performance and, in the case of a low-speed aircraft, to sacrifice some performance for lower manufacturing cost.

Using this procedure, the designer will have compared different design concepts, possibly using different materials, e.g., sheet metal versus composites or castings versus a built-up metal assembly. With each analysis conducted in accordance with the same general ground rules, e.g., lot sizes, design quantity, etc., the designer and management can be confident in the results.

3.3 Utilization of Learning Curve

The Learning Curve (LC) Theory, developed from historical manufacturing cost data, is a mathematical means of expressing the reduction in manufacturing labor as an aerospace program proceeds through the production phase. The LC theory states that "as the production quantity doubles, the labor required to produce a unit is reduced by a constant percentage." For example: For an 80 percent LC, the labor required to produce the second unit is 80 percent of that required to produce the first unit; the labor required for the fourth unit is 80 percent of that required for the second unit; etc. Table 3-1 provides examples of typical aerospace industry learning curves. Table 3-1 is useful for those designers for whom an individual company learning curve are not available.

The application of the learning curve varies among companies and the percent may be varied as a program progresses. In the early phases, a 70 percent LC may be used with a change to 85 percent as production progresses. Toward the end of the program labor turnover can result in a man-hour increase - i.e., a negative learning curve.

The LC has a different slope for the various manufacturing technologies, e.g., sheet-metal, machining, joining, and bench assembly. The learning curve factor used in cost-estimating depends on both the LC percentage and the design quantity. For example, the engineering cost analysis group at Lockheed-California Company uses the historically determined LC percentage for the technology involved and also uses a design quantity, the number of airplanes to be built, regardless of the number of identical parts per airplane. Occasionally, departmental realization (standard man-hours/actual man-hours) is used instead of the LC to analyze costs of high usage operations (such as riveting and nutplate or fastener installation) that are common to many parts or assemblies.

When comparing a proposed design to an existing design in production, reductions in labor cost o[illegible] during the "prior production" must be considered. For example:

Design quantity - 200 airplanes
Prior production - 100 airplanes

The cost analysis would compare the cost of "existing design" units 101 thru 200 to the cost of the "proposed design" units 1 thru 100.

Aerospace labor costs are normally collected by cost centers, each representing a different manufacturing technology, and are not traceable to individual parts or assemblies. Labor costs are for a production lot representing a "mix" of single usage and multiple usage parts or assemblies. From these data, learning curve slopes (%) are established for the various cost centers. When estimating the cost of aerospace parts or assemblies, the appropriate learning curve factor, provided in Table 3-2, is selected by the learning curve percentage for the technology involved and the design quantity, regardless of the quantity of parts or assemblies per airplane.

TABLE 3-1. TYPICAL INDUSTRY LEARNING CURVES

OPERATION	TYPICAL INDUSTRY LEARNING CURVE
Assembly, Controls	85%
Assembly, Electrical	80%
Assembly, Hydraulics, Pneumatic, etc.	85%
Functional Installation	65%
Plastic Fabrication	85%
Machining - Conventional	90%
Machining - Numerical Control	95%
Structural Assembly - Bench	85%
Structural Assembly - Floor	75%
Structural Assembly - Final	70%
Sheet Metal Fabrication	90%

NOTE: The above table has been included for use by designers who may not have company learning curve values readily available.

Use the above appropriate learning curve in Table 3-2 to obtain learning curve factor for design quantity involved.

TABLE 3-2

FACTORS TO CONVERT THE MC/DG 200TH UNIT COST TO THE CUMULATIVE AVERAGE COST FOR THE DESIGN QUANTITY AND LEARNING CURVE INVOLVED

DESIGN QUANTITY	LEARNING CURVE-%						
	95	90	85	80	75	70	65
1	1.48	2.25	3.48	5.50	9.00	15.00	27.00
10	1.33	1.79	2.47	3.48	5.04	7.53	11.67
25	1.25	1.59	2.05	2.71	3.68	5.13	7.43
50	1.19	1.44	1.79	2.22	2.85	3.76	5.14
100	1.13	1.30	1.52	1.80	2.18	2.73	3.51
200	1.08	1.17	1.30	1.45	1.66	1.95	2.36
350	1.04	1.08	1.14	1.22	1.33	1.48	1.70
500	1.01	1.02	1.05	1.09	1.15	1.24	1.38
750	0.98	0.96	0.96	0.96	0.97	1.01	1.09
1000	0.96	0.92	0.89	0.87	0.87	0.88	0.91

3.4 Cost Worksheet for Airframe Designers

Airframe designers can utilize the MC/DG data in a number of ways. When it is necessary to determine the total cost of an aircraft subassembly, the Cost Worksheet, shown in Table 3-3, has been developed and can be used at the discretion of the designer. This table enables the program recurring and nonrecurring costs to be determined and also the cost per aircraft.

3.4.1 Instructions for Use of Cost Worksheet

The following are instructions on utilizing this worksheet.

Step No.	Worksheet Column	Input	Procedure
1		Part no.	Enter identification, if available.
2		Description	Enter brief description, e.g., Stiffener, Zee, J section, etc.
3	1	Manufacturing Labor	From CED section determine man-hours per part at 200 units.
4	2	Learning curve (LC) factor	Based upon learning curve percentage and design quantity. Factor provided by user company.
5	3	TI&E labor	From MC/DG, enter RC for TI&E (man-hours).
6	4	Labor rate	Current manufacturing labor rate including direct labor fringe benefits and overhead charges.
7	5	Labor recurring costs (RC)	Product of Column 1 times Column 2 plus Column 3 times Column 4.
8	6	Material cost	Based upon furnished data in company utilizing MC/DG, enter material cost per part in dollars.
9	7	Recurring cost (RC) per part	Total of Columns 5 and 6.
10	8	Parts per aircraft	Number of identical parts per aircraft.
11	9	Design quantity	Number of aircraft in buy considered.
12	10	Program recurring cost (RC)	Product of Column 7 times Column 8 times Column 9.
13	11	Nonrecurring tooling cost (NRTC)	From MC/DG, enter NRTC in man-hours.
14	12	NRTC for TI&E	From MC/DG, enter NRTC for TI&E in man-hours.
15	13	Labor rate	See Column 3.
16	14	Program nonrecurring tooling costs (NRTC)	Columns 11 plus 12 times Column 13.
17	15	Program cost	Sum of Column 10 and Column 14.
18	16	Design quantity	See Column 9.
19	17	Cost per aircraft	Column 15 divided by Column 16.

TABLE 3-3

MC/DG COST WORKSHEET

PAGE ____ ____

DESIGN CONCEPT		RECURRING COST (RC)										NON-RECURRING COST (NRC)				PROGRAM COST		
		(L . LC + TIME) LR = LS + MS = RC . P/AC . DQ = PRC										(NRC + TIME) LR = PNRC				10 + 14 + DQ = COST/AC		
PART NO.	DESCRIPTION	LABOR MC/DG MH/PT (1)	LC FACTOR (2)	LABOR TIME MH/PT (3)	LABOR RATE $/MH (4)	LABOR RC $/PT (5)	MAT'L $/PT (6)	REC. COST/ PT. $ (7)	PARTS PER AC (8)	DES. QTY. (9)	PROG. RC $ (10)	NRC MC/DG MH (11)	NRC TIME MH (12)	LABOR RATE $/MH (13)	PROG. NRC $ (14)	PROG. COST $ (15)	DES. QTY. (16)	COST/ AC $ (17)
	TOTALS																	

REMARKS ______________________________

BY: ______________

DATE: ______________

SECTION 4
MANUFACTURING COST/DESIGN GUIDE DATA SECTIONS

4.1 Sheet Metal Section

This section contains format selection aids, identification of the types of parts analyzed for data to determine the manufacturing man-hour data, examples of how the data are utilized in airframe design and a set of sheet metal MC/DG formats. These formats are of 3 types; cost-driver effects (CDE), cost-estimating data (CED), and designer-influenced cost elements (DICE).

4.1.1 Format Selection Aids

Format selection aids are presented to provide the user with a building-block approach to determine manufacturing cost data for alternative designs or processes. The designer can review the format selection trees and identify those areas that have an impact on his design. The formats provide cost-driver effects (CDE) for qualitative guidance to lowest cost and cost-estimating data (CED) in man-hours for conducting trade studies.

Three selection aids are included in this Section. The first, Figure 4.1-1, provides designers with CED formats for straight and contoured lineal shapes and also panels. Upon consulting the selection aid, designers identify the part which is identical or similar to that being designed. Adjacent to each part shown in Figure 4.1-1, the format is indicated, e.g., for an aluminum channel; CED-A-4. Designer-influenced cost elements (DICE) are also indicated on Figure 4.1-1. The formats referred to in Figure 4.1-1 are the lowest cost processes.

Second, the selection aid, Figure 4.1-2, also guides the designer to the lowest cost process. CED-DICE-1 indicates, for example, the relative incremental costs of incorporating DICE when using various manufacturing processes. Selection aid, Figure 4.1-2, also indicates the effect of forming process and material and also the effect of cross section and material on the cost of various parts.

Third, the selection aid, Figure 4.1-3, is included because, the designer, when interacting with management or manufacturing, may find it necessary to select a process other than the lowest cost, due, for example, to facilities being committed for another airframe production run. The parts that can be produced by a single manufacturing process are therefore indicated on the selection aid.

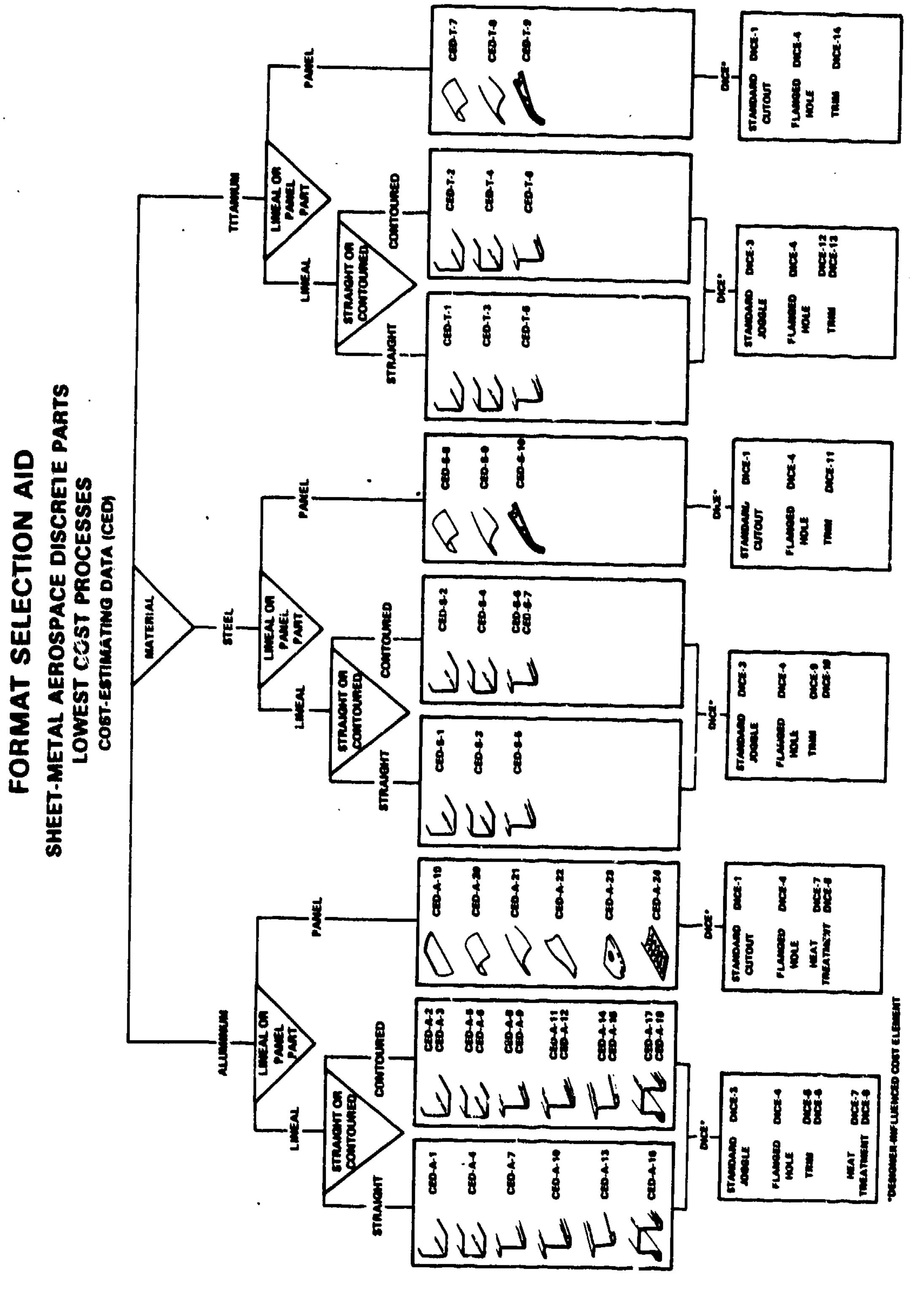

FORMAT SELECTION AID
SHEET-METAL AEROSPACE DISCRETE PARTS
LOWEST COST PROCESSES
COST-ESTIMATING DATA (CED)
MATERIAL
ALUMINUM
STEEL
TITANIUM
LINEAL OR PANEL PART
LINEAL
PANEL
STRAIGHT OR CONTOURED
STRAIGHT
CONTOURED
DICE*
STANDARD JOGGLE
STANDARD CUTOUT
FLANGED HOLE
TRIM
HEAT TREATMENT
*DESIGNER-INFLUENCED COST ELEMENT

FIGURE 4.1-1

FORMAT SELECTION AID

SHEET-METAL COST-DRIVER EFFECT (CDE) DATA

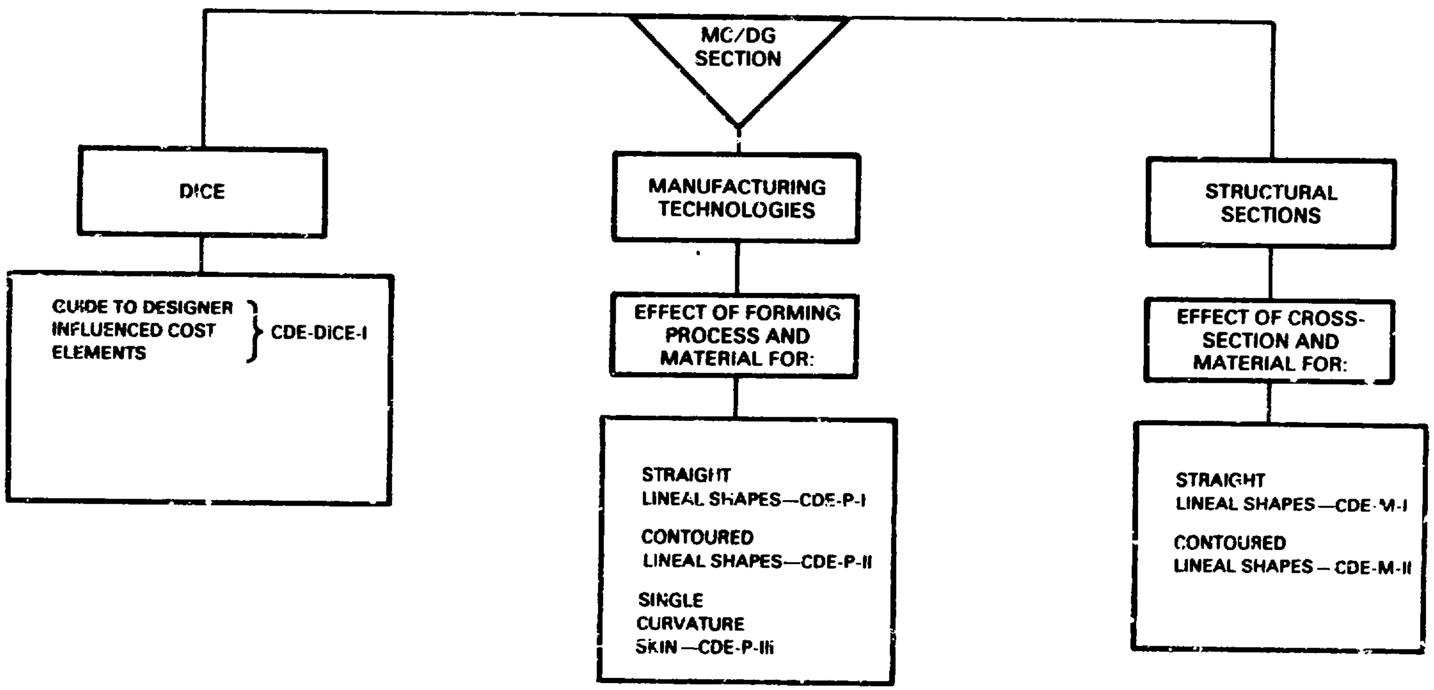


FIGURE 4.1-2

FORMAT SELECTION AID
COMPARISON OF SHEET-METAL STRUCTURAL SECTIONS
PRODUCED BY SAME MANUFACTURING METHOD

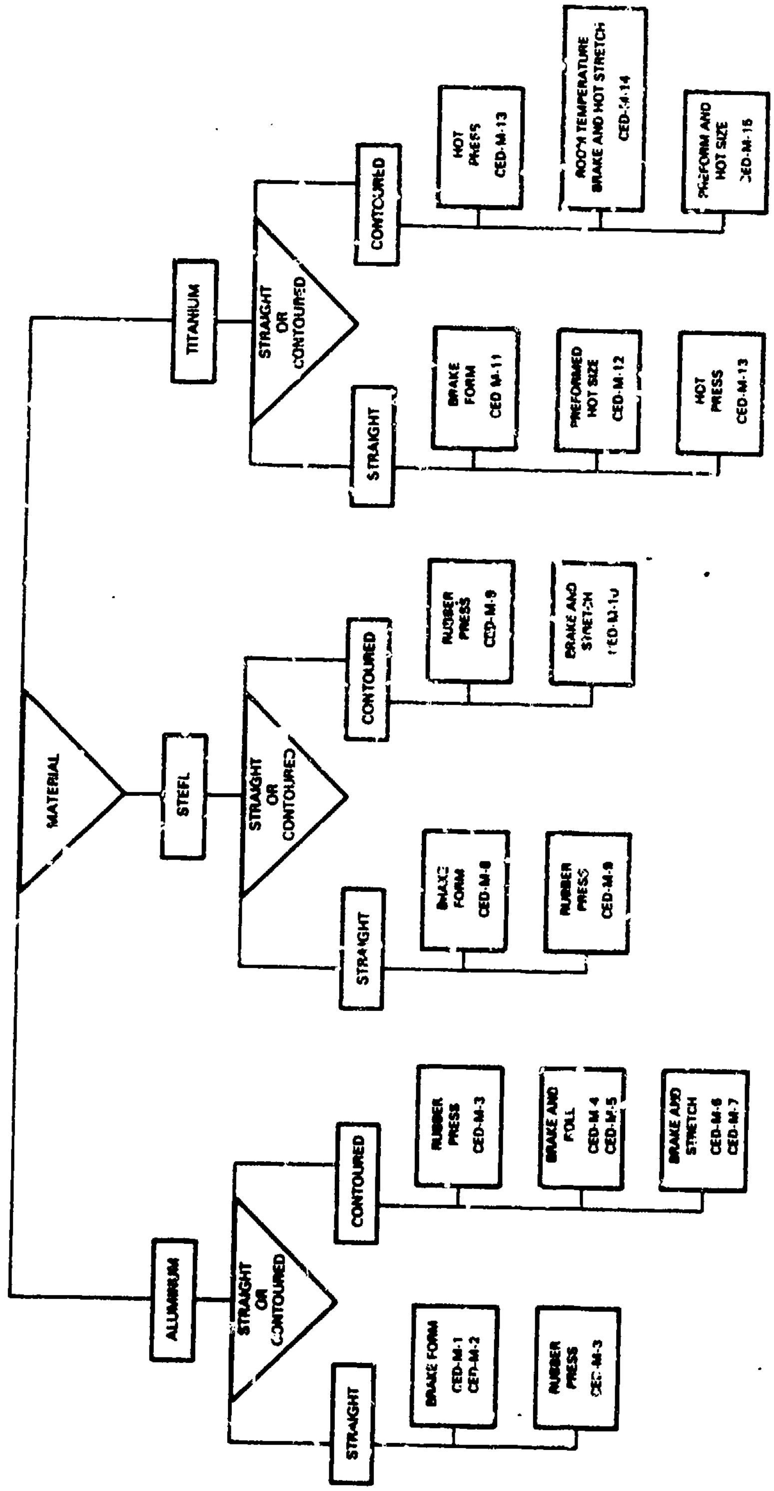


FIGURE 4.1-3

4.1.2 Building-Block Decisions Utilizing MC/DG

The method of analyzing the manufacturing man-hour data for aerospace discrete parts was discussed in Section 3.1.1. Having selected the material and candidate configurations, the designer determines the cost of manufacturing the base part and also designer-influenced cost elements (DICE). This is valid for panels and also lineal shapes such as stringers or stiffeners required to reinforce panels. DICE may, in some cases, be incorporated utilizing conventional manufacturing processes or, in other cases, special processes, but usually increase the cost of a part. The figures which follow indicate how the building-block method is applied at various levels of assembly development:

Figure 4.1-4: Unstiffened Panels and Lineal Shapes

Figure 4.1-5: Structurally Equivalent Assembled Panels Utilizing the Mechanically Fastened Assembly Section in the MC/DG

Figure 4.1-6: Typical Sheet Metal Ribs and Spars Manufactured from Sheet Metal.

This approach has been utilized in the trade studies on aluminum, titanium, and composite fuselage panels described in Section 4.8.

DECISION CONSIDERATIONS FOR SHEET-METAL DESIGNS

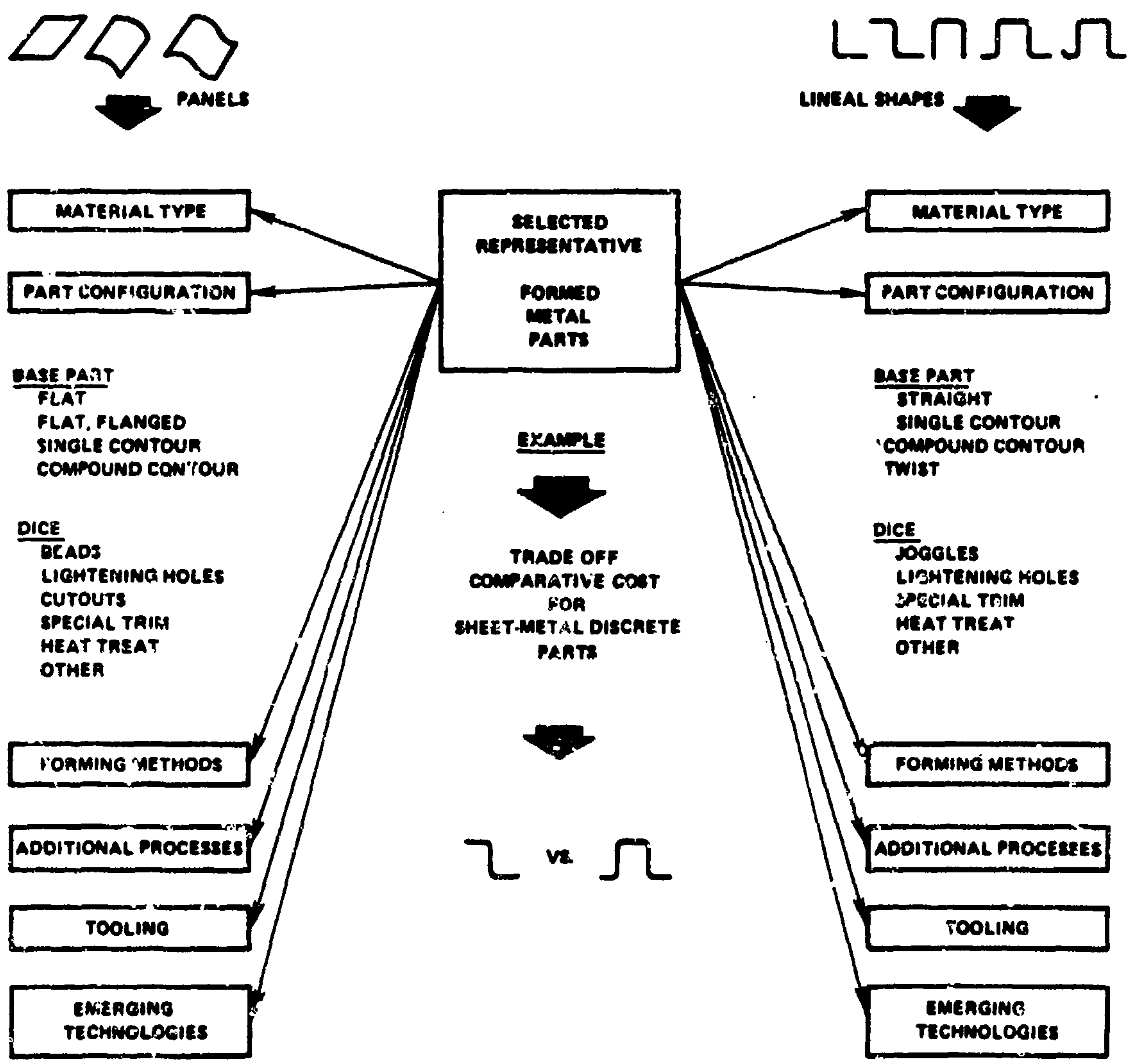


FIGURE 4.1-4

DECISION CONSIDERATIONS FOR SHEET-METAL DESIGNS UTILIZING MECHANICALLY FASTENED ASSEMBLIES SECTION

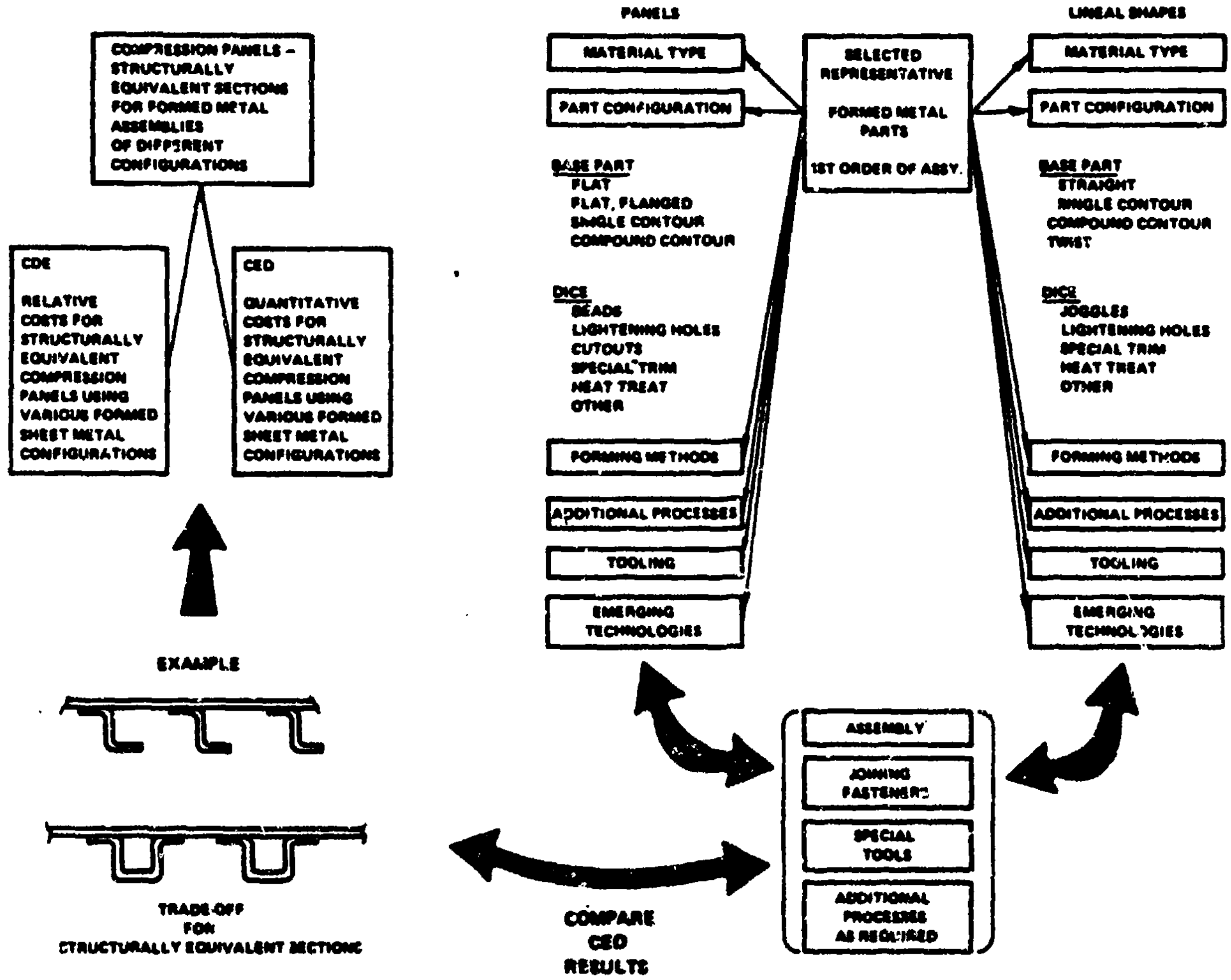


FIGURE 4.1-5

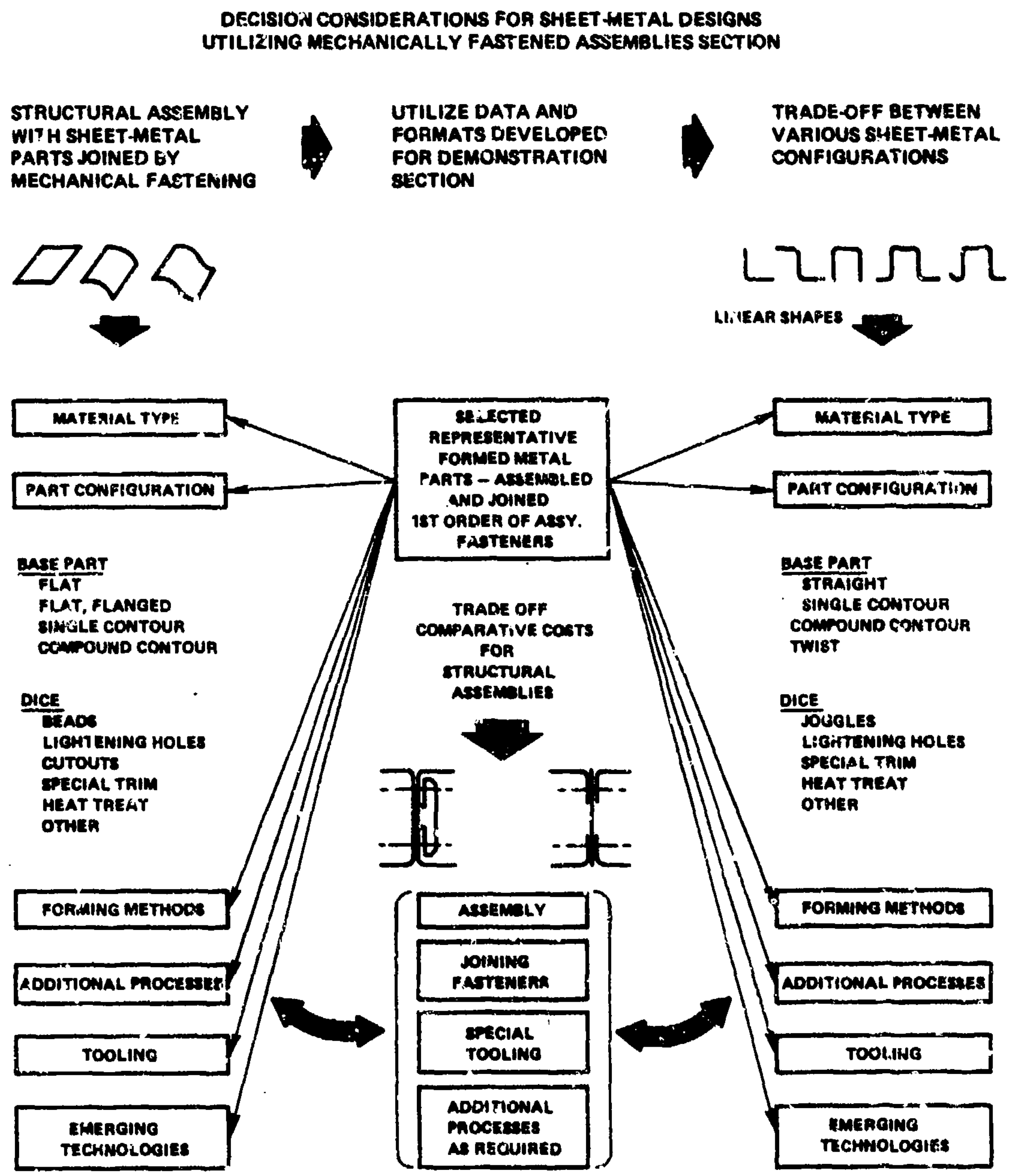

DECISION CONSIDERATIONS FOR SHEET-METAL DESIGNS
UTILIZING MECHANICALLY FASTENED ASSEMBLIES SECTION
STRUCTURAL ASSEMBLY WITH SHEET-METAL PARTS JOINED BY MECHANICAL FASTENING
UTILIZE DATA AND FORMATS DEVELOPED FOR DEMONSTRATION SECTION
TRADE-OFF BETWEEN VARIOUS SHEET-METAL CONFIGURATIONS
LINEAR SHAPES
MATERIAL TYPE
PART CONFIGURATION
SELECTED REPRESENTATIVE FORMED METAL PARTS – ASSEMBLED AND JOINED 1ST ORDER OF ASSY. FASTENERS
MATERIAL TYPE
PART CONFIGURATION
BASE PART
FLAT
FLAT, FLANGED
SINGLE CONTOUR
COMPOUND CONTOUR
DICE
BEADS
LIGHTENING HOLES
CUTOUTS
SPECIAL TRIM
HEAT TREAT
OTHER
TRADE OFF COMPARATIVE COSTS FOR STRUCTURAL ASSEMBLIES
BASE PART
STRAIGHT
SINGLE CONTOUR
COMPOUND CONTOUR
TWIST
DICE
JOGGLES
LIGHTENING HOLES
SPECIAL TRIM
HEAT TREAT
OTHER
FORMING METHODS
ADDITIONAL PROCESSES
TOOLING
EMERGING TECHNOLOGIES
ASSEMBLY
JOINING FASTENERS
SPECIAL TOOLING
ADDITIONAL PROCESSES AS REQUIRED
FORMING METHODS
ADDITIONAL PROCESSES
TOOLING
EMERGING TECHNOLOGIES

FIGURE 4.1-6

4.1.3 Examples of Utilization

These examples demonstrate how the data generated are utilized on a specific design problem. The example shows how to identify applicable formats, how to extract data from the formats, and provides a discussion on how the data are used to determine the part cost in man-hours or dollars. The MC/DG cost worksheet can be used to record the cost data for easy reference and to determine the total program cost.

4.1.3.1 Utilization Example for Sheet Metal Aluminum Fairing

Problem Statement

Determine manufacturing cost (man-hours) of an aluminum (2024) fairing measuring 36" x 12" (see sketch below).

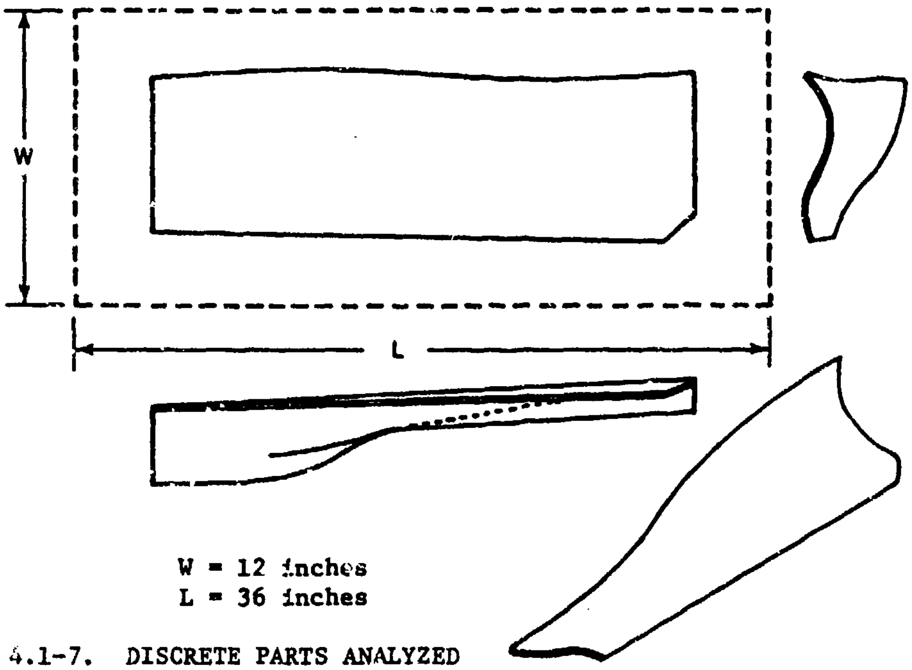


FIGURE 4.1-7. DISCRETE PARTS ANALYZED

Procedure

The following procedure is used to determine the manufacturing cost (man-hours) for the aluminum fairing.

1. Utilize The Format Selection Aid for Sheet Metal Lowest Cost Processes (see Figure 4.1-1).
2. Determine format to use. In this case, Format CED-A-22 is required (see Figure 4.1-8).

3. Study the format to determine the parameters and conditions necessary for its use and relate these to the part. For CED-A-22, area (ft^2) is needed, in this case 3 ft^2.

4. From CED-A-22, read values for the recurring cost and nonrecurring tooling cost (NRTC):

   - Recurring cost at unit 200 = 0.71 man-hours per part
   - NRTC = 275 man-hours for 200 parts or 275/200 = 1.375 man-hours per part
   - The learning curve factor (Table 4.1-1) to convert unit cost at 200 to cumulative average cost for a 90 percent curve and a quantity of 200 is 1.17 (see Table 4.1-1).

   The base-part manufacturing cost is thus 0.71 (1.17) + 1.38 + 2.21 man-hours per part.

5. Check for applicable Designer-Influenced Cost Elements (DICE). The format indicates that no DICE are applicable for the drop hammer manufacturing method of producing this part. This implies that the calculated base-part cost is the final total manufacturing cost for the discrete part (excluding direct material cost).

6. Obtain the cost (dollars) by multiplying 2.21 man-hours by the applicable labor rate at your company. If material cost could be a factor, for example, if this fairing were being compared with a fiberglass fairing, material cost would be added to the manufacturing cost.

7. For the cost of test, inspection and evaluation (TI&E), reference should be made to MC/DG Section 4.7.1 "TI&E for Sheet Metal" and the example on page 4.7.1-4.

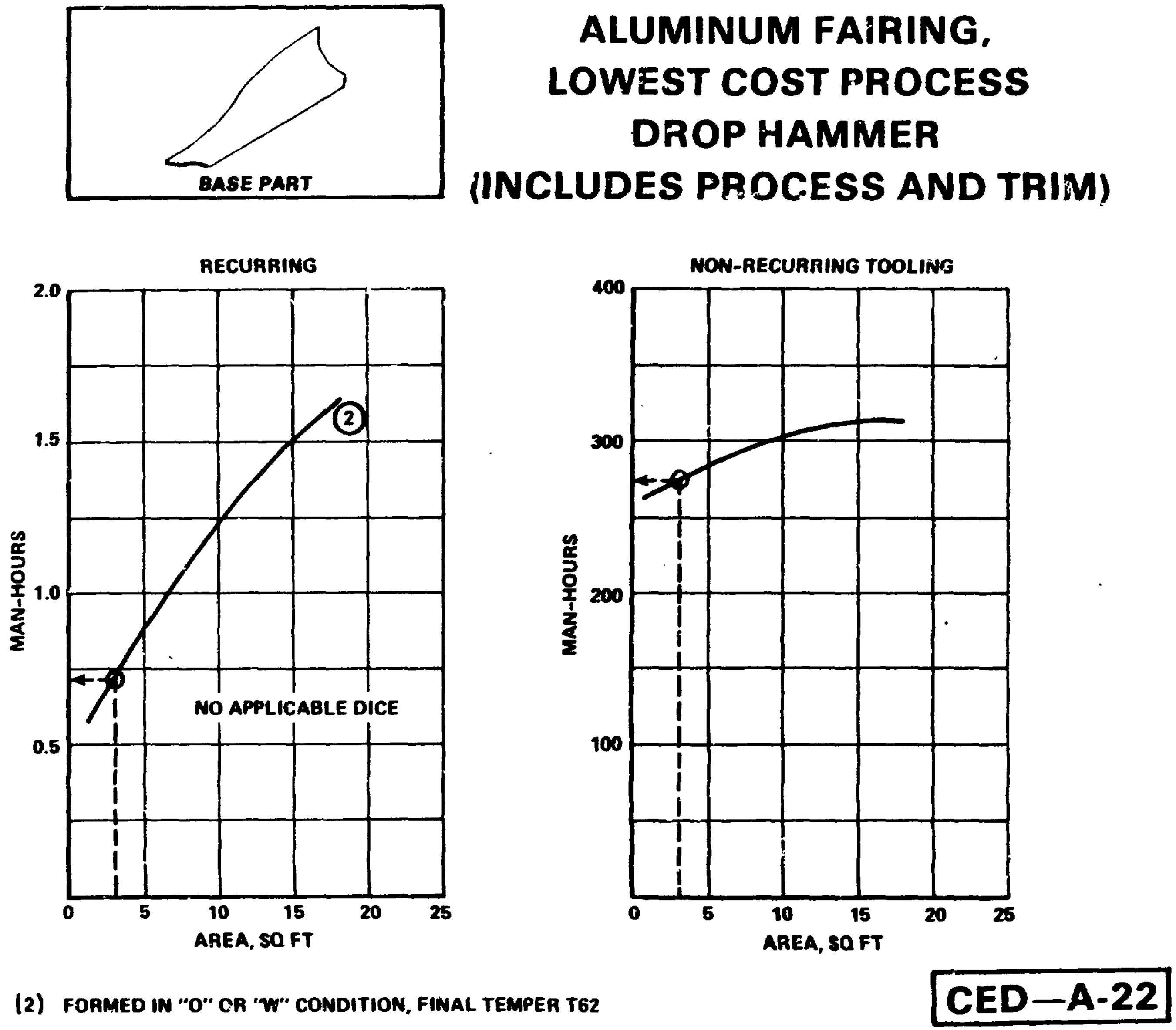


FIGURE 4.1-8. FORMAT USED IN EXAMPLE

TABLE 4.1-1

FACTORS TO CONVERT THE MC/DG 200TH UNIT COST TO THE CUMULATIVE AVERAGE COST FOR THE DESIGN QUANTITY AND LEARNING CURVE INVOLVED

DESIGN QUANTITY	LEARNING CURVE-%						
	95	90	85	80	75	70	65
1	1.48	2.25	3.48	5.50	9.00	15.00	27.00
10	1.33	1.79	2.47	3.48	5.04	7.53	11.67
25	1.25	1.59	2.05	2.71	3.68	5.13	7.43
50	1.19	1.44	1.79	2.22	2.85	3.76	5.14
100	1.13	1.30	1.52	1.80	2.18	2.73	3.51
200	1.08	1.17	1.30	1.45	1.66	1.95	2.36
350	1.04	1.08	1.14	1.22	1.33	1.48	1.70
500	1.01	1.02	1.05	1.09	1.15	1.24	1.38
750	0.98	0.96	0.96	0.96	0.97	1.01	1.09
1000	0.96	0.92	0.89	0.87	0.87	0.88	0.91

4.1.3.2 Utilization Example for Sheet Metal Steel Skin

Problem Statement

Determine manufacturing cost (man-hours) of the PH15-7Mo steel skin, having circular curvature and two cutouts. The dimensions are as shown in the sketch below.

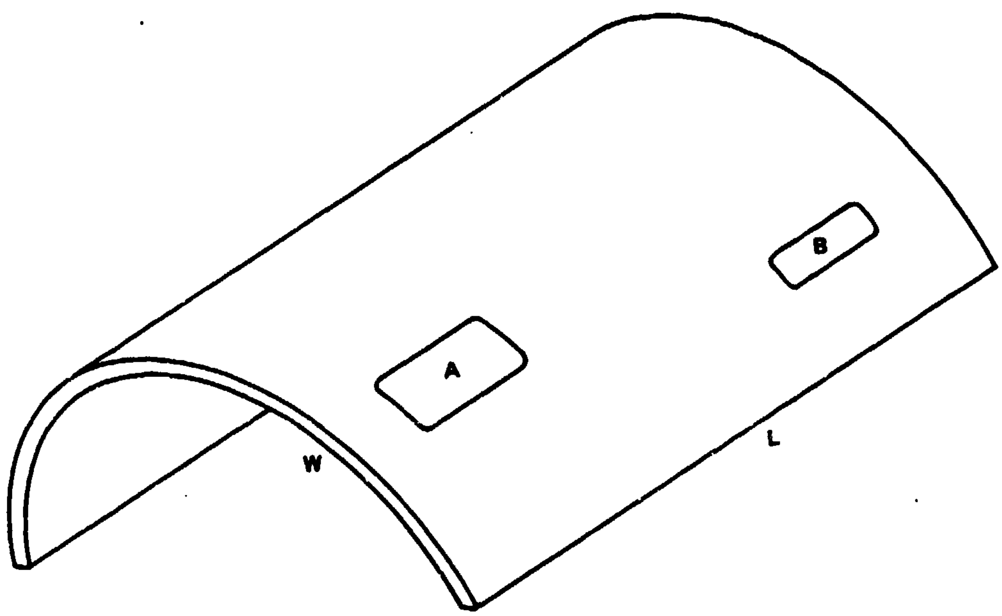


FIGURE 4.1-9. DISCRETE PART ANALYZED

Procedure

The procedure to determine the manufacturing cost (man-hours) of the steel skin is presented below:

1. Utilize Format Selection Aid (Figure 4.1-1) for Sheet Metal Lowest Cost Processes.
2. Determine the formats to use. In this case, Formats CED-S-8 (Figure 4.1-10) for skin and DICE-1 (Fig. 4.1-11) for cutouts.
3. Study the formats to determine the parameters and conditions necessary for their use. In this case, area, in square feet, in required., i.e., 15 ft^2.

4. Determine from CED-S-8 (Fig. 4.1-10), the base part recurring and nonrecurring tooling costs (NRTC) in man-hours:
   - Recurring cost at unit 200 = 1.55 man-hours per part
   - NRTC = 74 man-hours for 200 parts = 0.37 man-hours per part
   - The learning curve factor = 1.17 (Table 4.1-1). Therefore, the base part manufacturing cost is: 1.55 (1.17) + 0.37 - 2.18 man-hours.
5. Analyze manufacturing cost for Designer-Influenced Cost Elements (DICE). For this discrete part, cutouts (DICE-E) are called out on drawing. Format CED-S-8 indicates that DICE-E is applicable for the Farnham Roll manufacturing method. Therefore, Format DICE-1 (Fig. 4.1-11) is required to determine the manufacturing cost of the cutouts.

   DICE-1 indicates that a standard cutout requires 0.036 man-hours per foot of perimeter, i.e.,
   - 2 feet of perimeter = 0.072 man-hours
   - 3 feet of perimeter = 0.108 man-hours.
6. Add DICE man-hours to the base-part cost to determine the manufacturing cost for the discrete part (not including direct material cost):

   2.18 + 1.17 (0.072 + 0.108) = 2.39 man-hours per part.
7. For the cost of test, inspection and evaluation (TI&E), reference should be made to MC/DG Section 4.7.1 "TI&E for Sheet Metal" and the example on page 4.7.1-8.

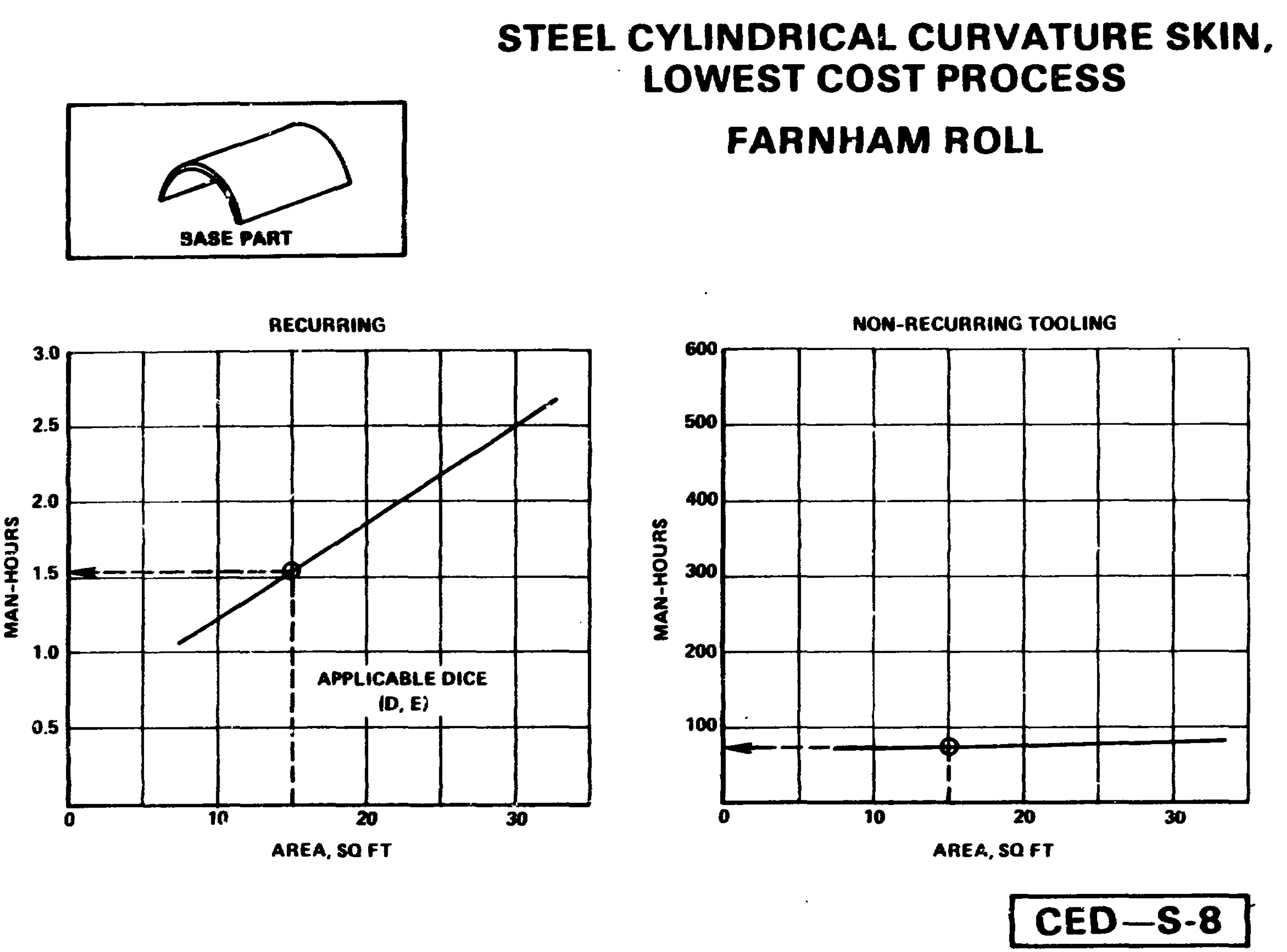


FIGURE 4.1-10. FORMAT USED IN EXAMPLE

SHEET-METAL AEROSPACE DISCRETE PARTS

DICE MAN-HOURS

DICE		ALUMINUM 2024	STEEL PH15-7Mo	TITANIUM 6Al-4V
A	HEAT TREATMENT[1]	T62: 0.8 X BASE PART COST T81: 0.1 X BASE PART COST	NOT APPLICABLE	NOT APPLICABLE
B	STANDARD JOGGLE	0.008 + (0.006 X N*)	0.008 + (0.006 X N) COLD 0.011 + (0.018 X N) HOT	0.011 + (0.018 X N)
C	STANDARD FLANGED HOLE	0.010 + (0.010 X N*)	0.010 + (0.010 X N)	0.010 + (0.010 X N)
D	SPECIAL LINEAL TRIM	PER FOOT: 0.021 MAN-HOURS**	PER FOOT: 0.049 MAN-HOURS**	PER FOOT: 0.061 MAN-HOURS**
E	STANDARD CUTOUT	0.024 MAN-HOURS PER FOOT OF PERIMETER	0.036 MAN-HOURS PER FOOT OF PERIMETER	0.036 MAN-HOURS PER FOOT OF PERIMETER

*N = NUMBER OF JOGGLES OR FLANGED HOLES.

**COST INCLUDES AMORTIZED TOOLING, AMORTIZED OVER 200 UNITS

1: THIS IS A COMPOSITE FACTOR FOR ALL SHAPES AND SIZES. FOR MORE DETAILS SEE DICE 7 OR DICE 8.

FIGURE 4.1-11. FORMAT USED IN EXAMPLE

DICE-1

4.1.3.3 Utilization Example for Titanium Stiffener or Stringer

Problem Statement

Determine manufacturing cost (man-hours) of a straight 6Al-4V titanium "Z" section stringer having dimensions shown on Figure 4.1-12.

Procedure

The following procedure is used to determine the manufacturing cost (man-hours) of the titanium stiffener.

1. Utilize the Format Selection Aid (Fig. 4.1-1) for Sheet-Metal Lowest Cost Processes.
2. Determine the appropriate format for the base part. In this case, Format CED-T-5 (Fig. 4.1-13) is required.
3. Study the format to determine the parameters and conditions required for use. In this case, part length, in feet, and bend radius, are needed. For the purposes of this example, consider that either of the bend radius ranges indicated on the format could be used and determine which design would be the lowest cost to manufacture. Thus, we have the following two cases for the part:

   (a) Part length = 84 in. = 7 ft.
   Bend radius (R) $\geq$ 5t

   (b) Part length = 84 in. = 7 ft.
   Bend radius (R) = 2t $\leq$ R $\leq$ 5t.

4. Determine the base-part recurring and nonrecurring tooling costs (NRTC) in man-hours, for each case using CED-T-5 and the learning curve factor of 1.17 from Table 4.1-1.

   (a) Using curve (1)

   - Recurring cost at unit 200 = 0.55 man-hour per part
   - NRTC = 60 man-hours per 200 parts
     = 0.3 man-hours per part.

   Base part cost = 0.55 (1.17) + 0.3 = 0.94 man-hours per part.

   (b) Using curve (2)

   - Recurring cost at unit 200 = 2.05 man-hours per part
   - NRTC = 285 man-hours per 200 parts
     = 1.425 man-hours per part

   Base part cost = 2.05 (1.17) + 1.425 = 3.82 man-hours per part.

5. Check for applicable DICE. The example (Fig. 4.1-12) has flanged lightening holes (DICE-C) and trim prior to forming (DICE-F).

   For Case (a), Format CED-T-5 (Fig. 4.1-13) indicates both DICE-C and DICE-F are applicable to the brake forming method.

   For Case (b), the format indicates that no DICE are applicable for the preform/hot size method, as this method permits inclusion of the DICE at negligible additional cost. However, in the case of the brake forming operation, the DICE require additional operations. Thus, Case (b) has no additional cost for the flanged holes and the trim.

   To determine DICE costs for Case (a) again utilize the Format Selection Aid (Fig. 4.1-1) to determine that formats DICE-3 (Fig. 4.1-14) and DICE-11 (Fig. 4.1-15) are applicable. The parameters required are the number of flanged holes (DICE-3) and perimeter trim (DICE-11). Eight flanged holes are required in the airframe part and the perimeter trim required is approximately 180 inches. The DICE costs are:

   - Flanged holes: 0.09 man-hour per part
   - Trim prior to forming: 0.455 man-hour per part.

6. Determine total manufacturing costs (man-hours), excluding direct material cost.

   - Case (a): 1.17 (0.55 + 0.09 + 0.455) + 0.3 = 1.58 man-hours
   - Case (b): 3.82 man-hours.

   This shows that it is less costly to produce the part with a bend radius of ≥ 5t, if the design constraints permit.

7. To determine the cost of test, inspection and evaluation (TI&E), refer to MC/DG Section 4.7.1 "TI&E for Sheet Metal" and the example on page 4.7.1-12.

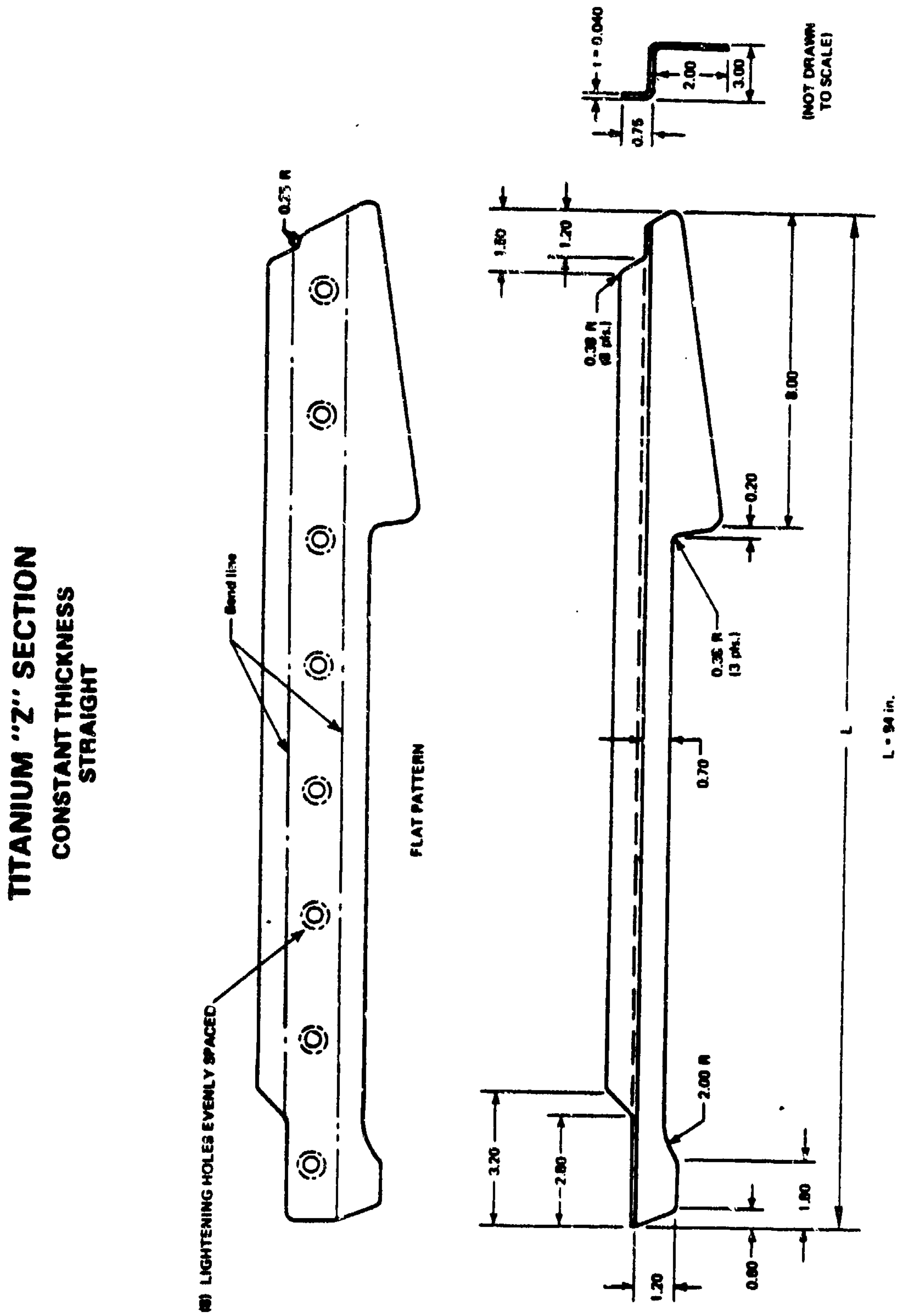
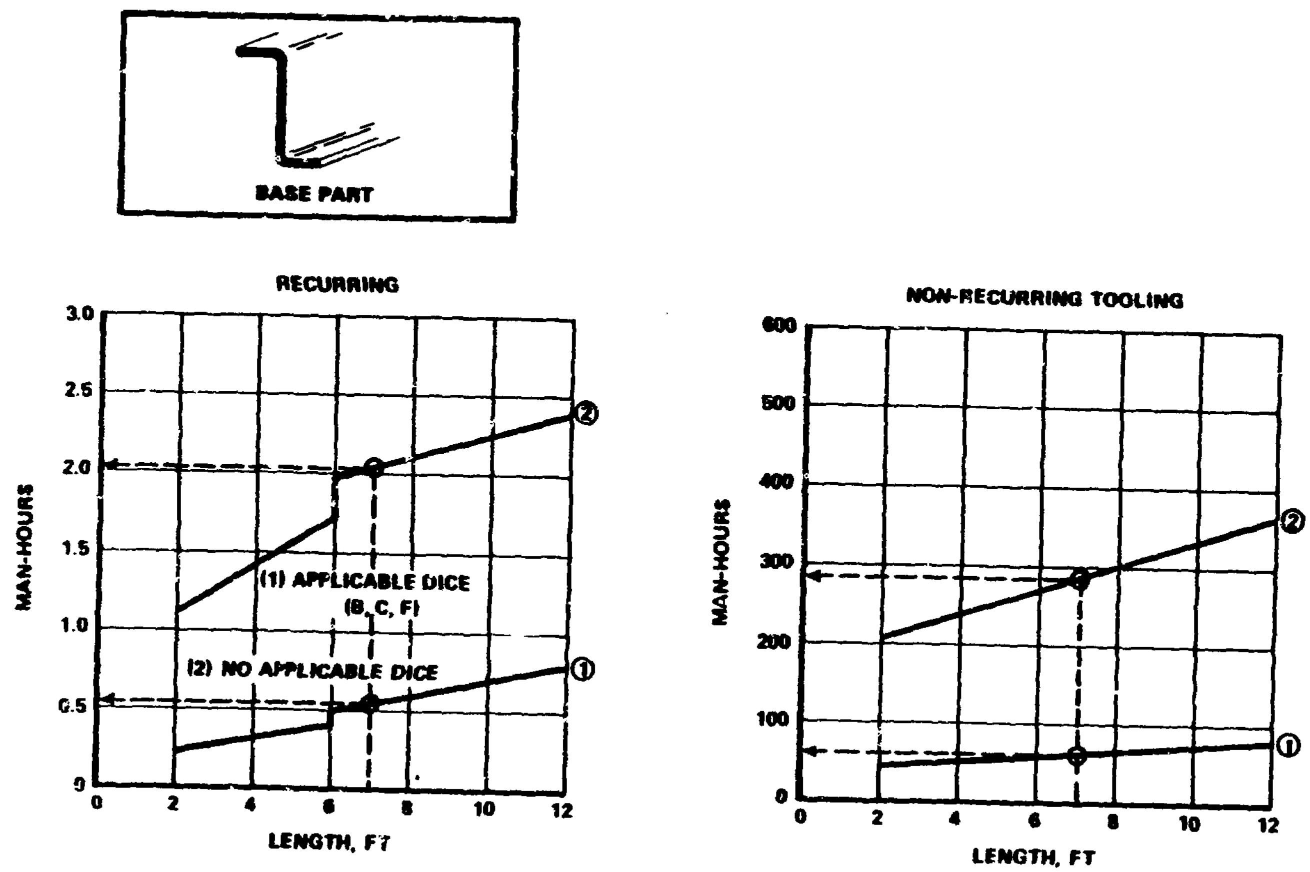


FIGURE 4.1-12. DISCRETE PART ANALYZED

TITANIUM ZEE, STRAIGHT MEMBER, LOWEST COST PROCESS

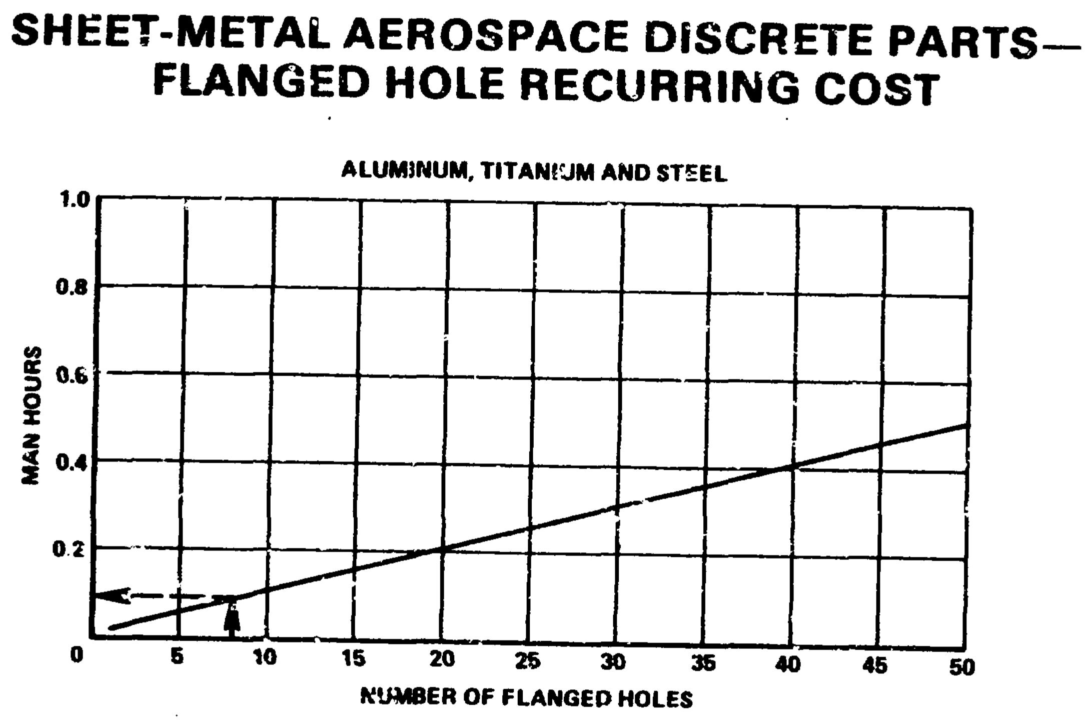
BRAKE FORM AND PREFORM/HOT SIZE



(1) ROOM TEMPERATURE BRAKE FORM, MINIMUM BEND RADIUS = 5t
(2) PREFORM/HOT SIZE, MINIMUM BEND RADIUS = 2t

CED-T-5

FIGURE 4.1-13. FORMAT USED IN EXAMPLE



DICE-3

FIGURE 4.1-14. FORMAT USED IN EXAMPLE

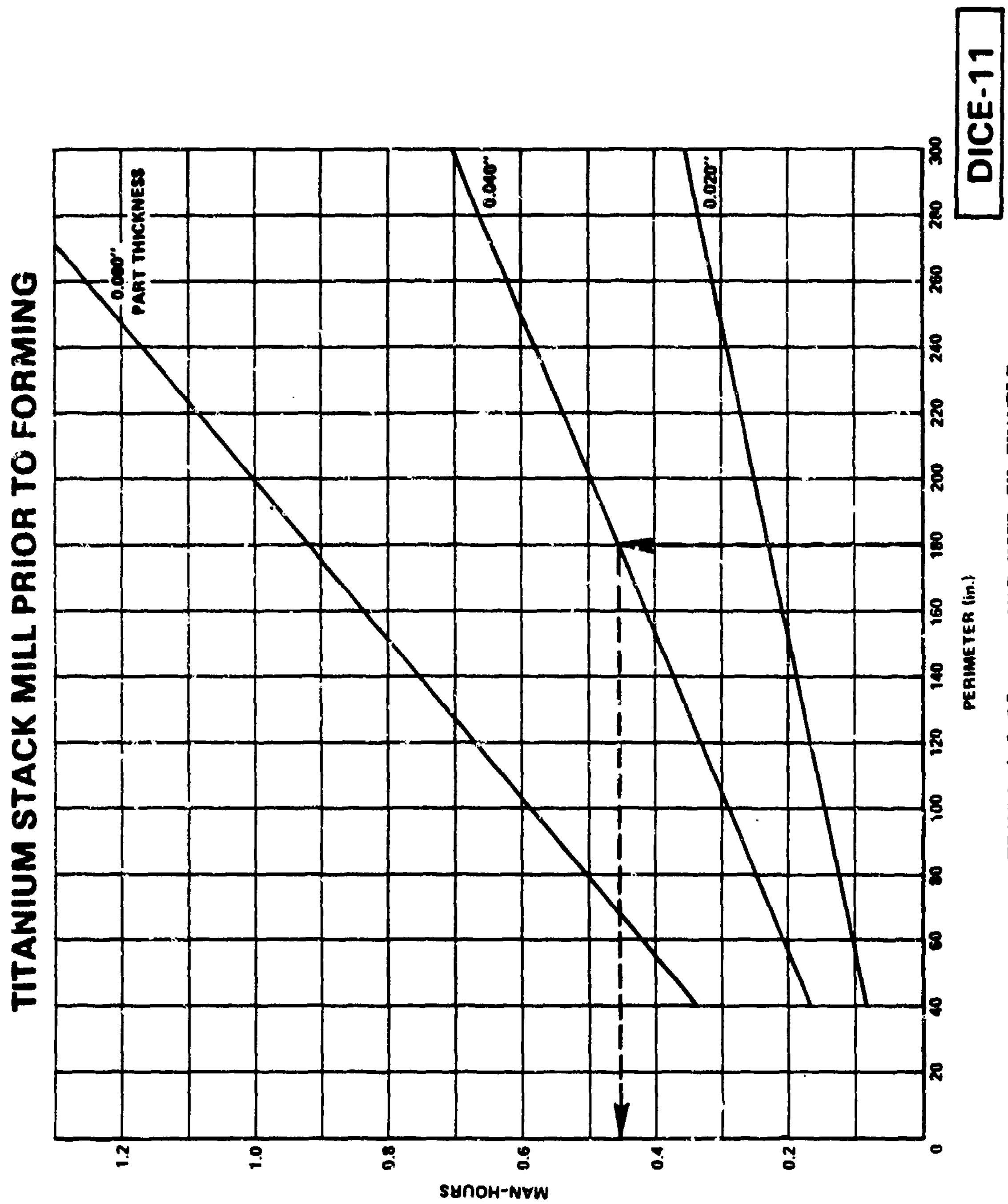


FIGURE 4.1-15. FORMAT USED IN EXAMPLE

4.1.4 Sheet Metal Parts Analyzed

To develop the manufacturing man-hour data to construct Cost-Estimating Data (CED) and Cost-Driver Effect (CDE) formats for sheet metal discrete parts, it was necessary to analyze each configuration, firstly, as a base part and, secondly, the designer-influenced cost elements (DICE) necessary to modify the base part to a usable form.

The base parts analyzed for aluminum, titanium, and steel materials are shown in Figures 4.1-16 to 4.1-22. The manufacturing methods are indicated on each figure for each group of base parts, e.g., for straight stiffeners and stringers in aluminum, brake forming, or the rubber press can be used. The following figures also indicate the range of sizes studied, e.g., 24 to 144 inches for titanium stiffeners and stringers.

The formats present the designer with man-hours for the lowest cost manufacturing method. In many cases, the designer is only concerned that the design represents the lowest cost process. However, the data for the other manufacturing methods indicated are also provided for use in cases where facilities may be committed or may not exist within the company using the MC/DG.

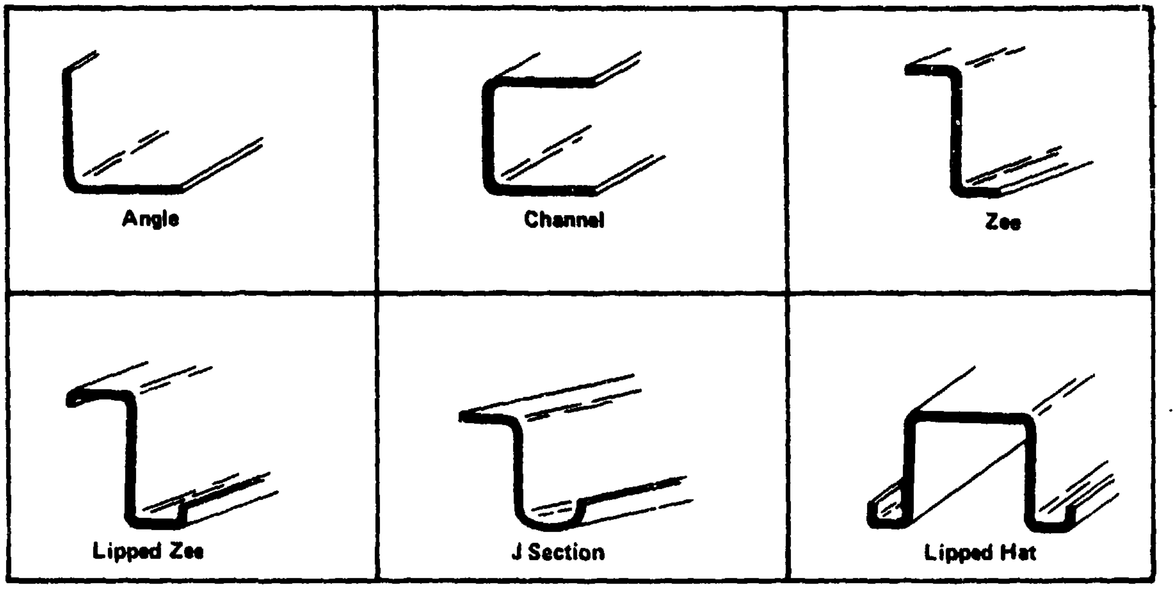
Examples of the discrete parts studied are listed below and are shown in Figures 4.1-23 to 4.1-34.

TABLE 4.1-2. EXAMPLES OF SHEET-METAL AEROSPACE DISCRETE PARTS ANALYZED

Part Code	Material	Description
MC/DG-A-1A	Aluminum	Constant Section, Straight Angle
MC/DG-A-2A	Aluminum	Constant Section, Straight Channel
MC/DG-A-4B	Aluminum	Constant Section, Curved Lipped Zee
MC/DG-A-5B	Aluminum	Constant Section, Curved "J"
MC/DG-A-9	Aluminum	Constant Thickness, Non-Circular Curvature Skin
MC/DG-A-11	Aluminum	Compound Curvature Fairing
MC/DG-A-12	Aluminum	Rib
MC/DG-A-13	Aluminum	Flat Beaded Panel
MC/DG-S-1B	Steel	Constant Section, Curved Angle
MC/DG-S-2B	Steel	Constant Section, Curved Channel
MC/DG-T-3A	Titanium	Constant Section, Straight Zee
MC/DG-T-5	Titanium	Frame

SHEET METAL AEROSPACE BASE PARTS

ALUMINUM STIFFENERS AND STRINGERS



Part Lengths

24" to 144"

Manufacturing Methods

Straight Parts
- Brake Form
- Rubber Press

Contoured Parts
- Brake/Buffalo Roll
- Brake/Stretch
- Rubber Press

FIGURE 4.1-16. TYPES OF BASE PARTS ANALYZED

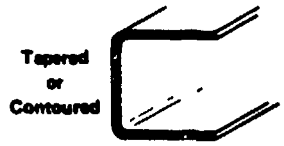
SHEET METAL AEROSPACE BASE PARTS

ALUMINUM RIBS (TYPICAL)

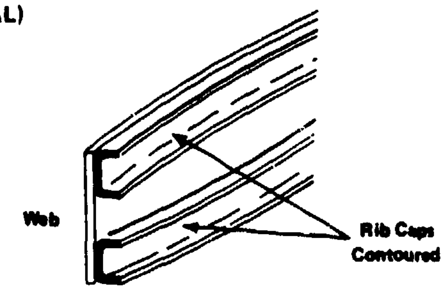
10" x 4" to 30" x 12"

Manufacturing Methods

- Die Form
- Rubber Press



Part Sizes



Length: 24" to 144"

Straight

- Brake Form
- Rubber Press

Contoured

- Brake/Buffalo Roll
- Brake/Stretch
- Rubber Press

ALUMINUM FAIRING

Part Sizes

12" x 12" to 36" x 72"

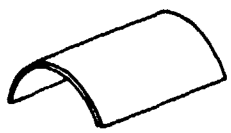
Manufacturing Methods

- Drop Hammer

FIGURE 4.1-17. TYPES OF PARTS ANALYZED

SHEET METAL AEROSPACE BASE PARTS

ALUMINUM SKIN PANELS



Cylindrical Contour

- Farnham Roll
- Stretch Form

Panel Sizes

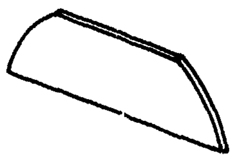
12" x 48" to 48" x 144"

Manufacturing Methods

Compound Contour

- Stretch Form

ALUMINUM WEBS AND DOUBLERS

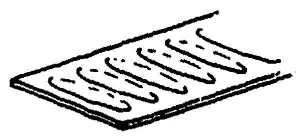


12" x 24" to 48" x 240"

- Routing

Part Sizes

Manufacturing Methods



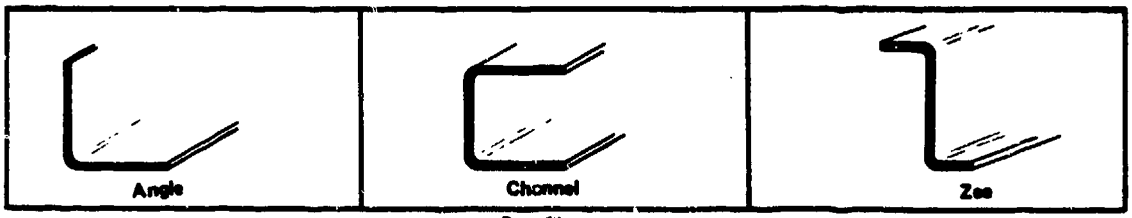
8" x 24" to 36" x 144"

- Rubber Press

FIGURE 4.1-18. TYPES OF PARTS ANALYZED

SHEET METAL AEROSPACE BASE PARTS

TITANIUM STIFFENERS AND STRINGERS



Part Size

Length: 24" to 144"

Manufacturing Methods

Straight Parts

- Brake Form – Room Temperature
- Preform/Hot Size
- Hot Press

Contoured Parts

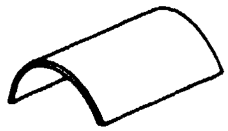
- Brake Form – Room Temperature and Hot Stretch
- Preform/Hot Size
- Hot Press

FIGURE 4.1-19. TYPES OF BASE PARTS ANALYZED

SHEET METAL AEROSPACE BASE PARTS

TITANIUM SKIN PANEL

Cylindrical Contour



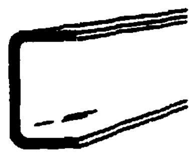
Panel Sizes

24" x 48" to 48" x 96"

Manufacturing Methods

- Creep Form
- Farnham Roll
- Hot Size
- Brake Form

TITANIUM RIBS AND FRAMES (TYPICAL)



Part Sizes

4" x 12" to 18" x 72"

Length: 24" to 144"

Manufacturing Methods

- Preform/Hot Size
- Hot Press

Straight

- Brake Form – Room Temperature
- Preform/Hot Size
- Hot Press

Contoured

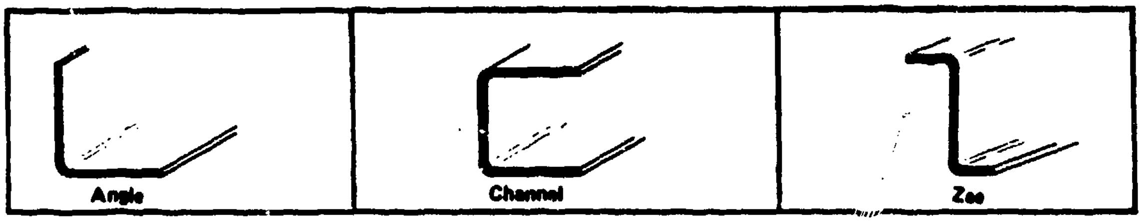
- Brake Form – Room Temperature and Hot Stretch
- Preform/Hot Size
- Hot Press

FIGURE 4.1-20. TYPES OF PARTS ANALYZED

FTR450261000U
3 Jan 1983

SHEET METAL AEROSPACE BASE PARTS

STEEL STIFFENERS AND STRINGERS



Part Sizes

Length: 24" to 144"

Manufacturing Methods

Straight Parts	Contoured Parts
• Brake Form	• Brake/Stretch
• Rubber Press	• Rubber Press

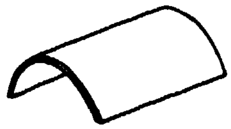
Note: All forming carried out at room temperature.

FIGURE 4.1-21. TYPES OF BASE PARTS ANALYZED

SHEET METAL AEROSPACE BASE PARTS

STEEL SKIN PANEL

Cylindrical Contour



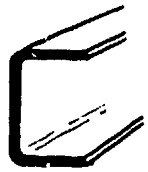
Panel Sizes

24" x 48" to 48" x 96"

Manufacturing Methods

- Stretch Form
- Brake Form
- Farnham Roll

STEEL RIBS AND FRAMES (TYPICAL)



Part Sizes

4" x 12" to 18" x 72"

Length: 24" to 144"

Manufacturing Methods

- Rubber Press

Straight

- Brake Form
- Rubber Press

Contoured

- Brake/Stretch
- Rubber Press

Note: All forming carried out at room temperature.

FIGURE 4.1-22. TYPES OF PARTS ANALYZED

ALUMINUM ANGLE
CONSTANT SECTION
STRAIGHT

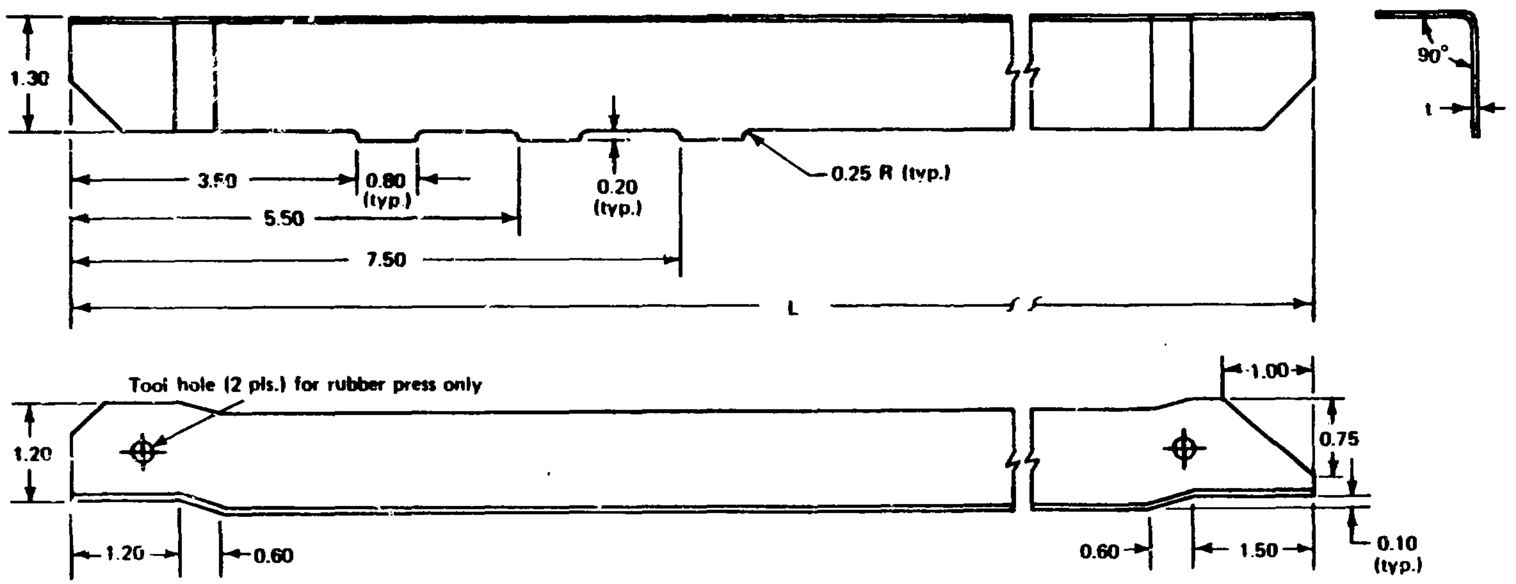
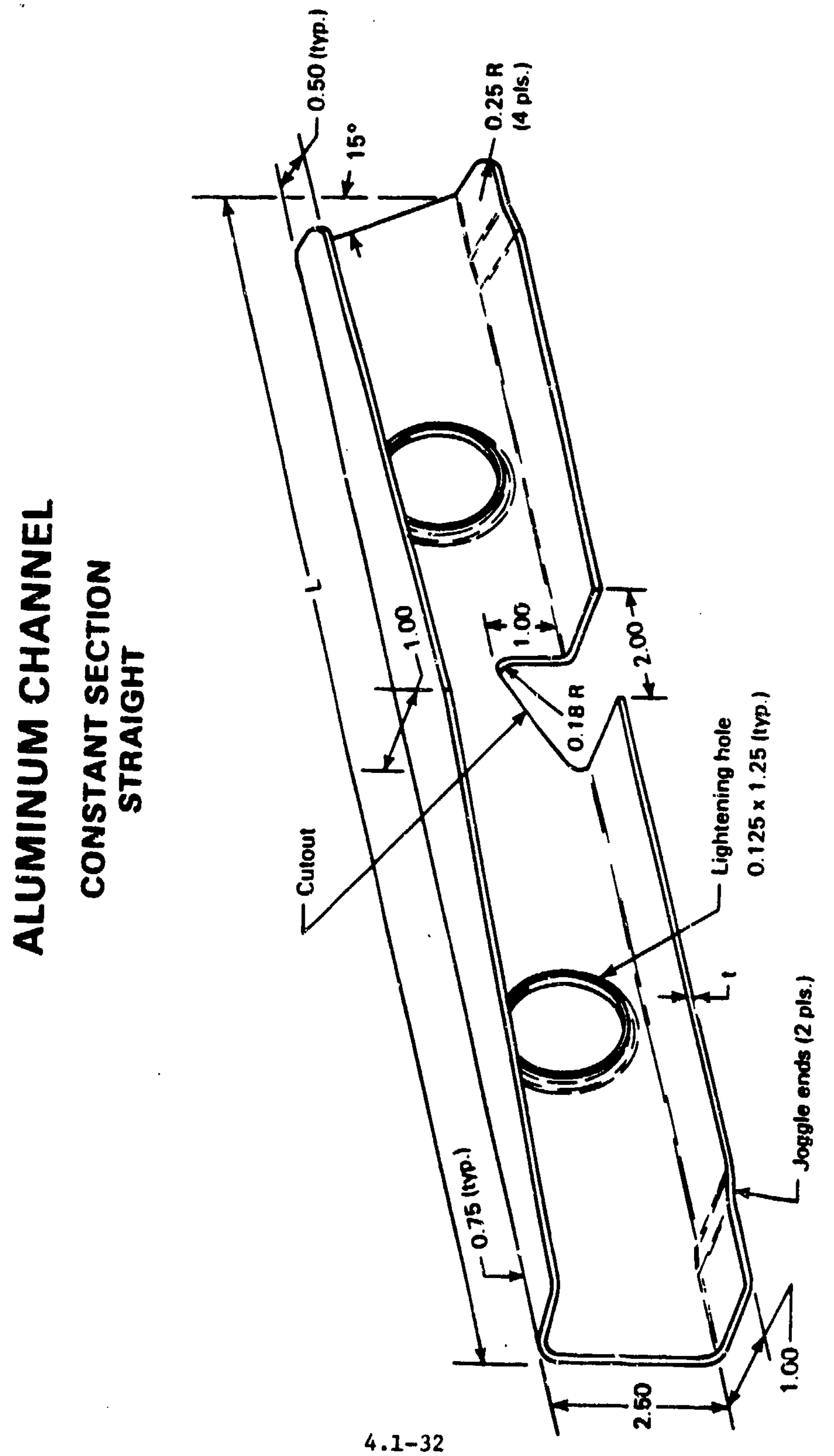


FIGURE 4.1-23. EXAMPLE OF SHEET METAL DISCRETE PART ANALYZED

MC/DG-A-1A



MC/DG-

FIGURE 4.1-24. EXAMPLE OF SHEET METAL DISCRETE PART ANALYZED

MC/DG-A-4B

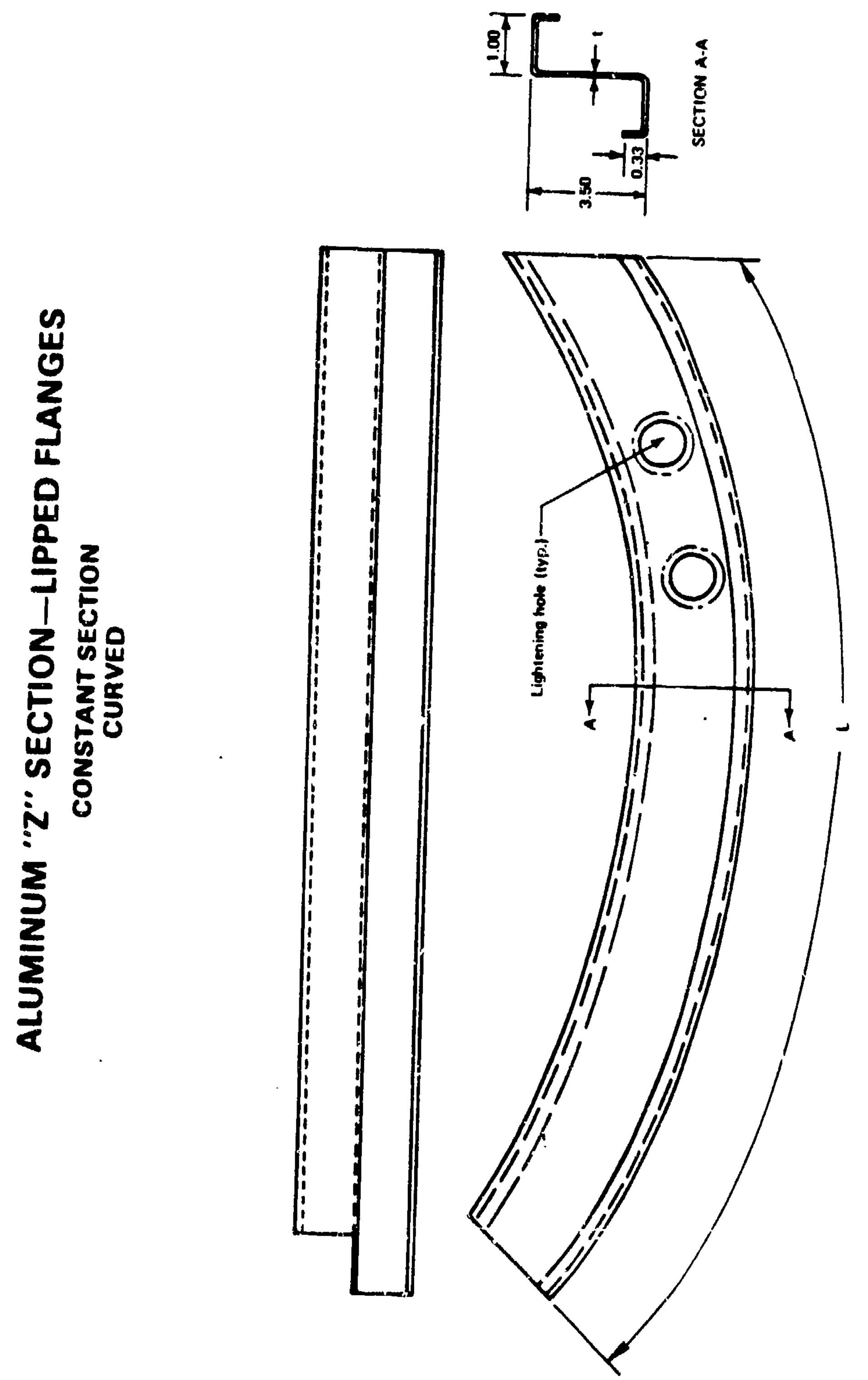


FIGURE 4.1-25. EXAMPLE OF SHEET METAL DISCRETE PART ANALYZED

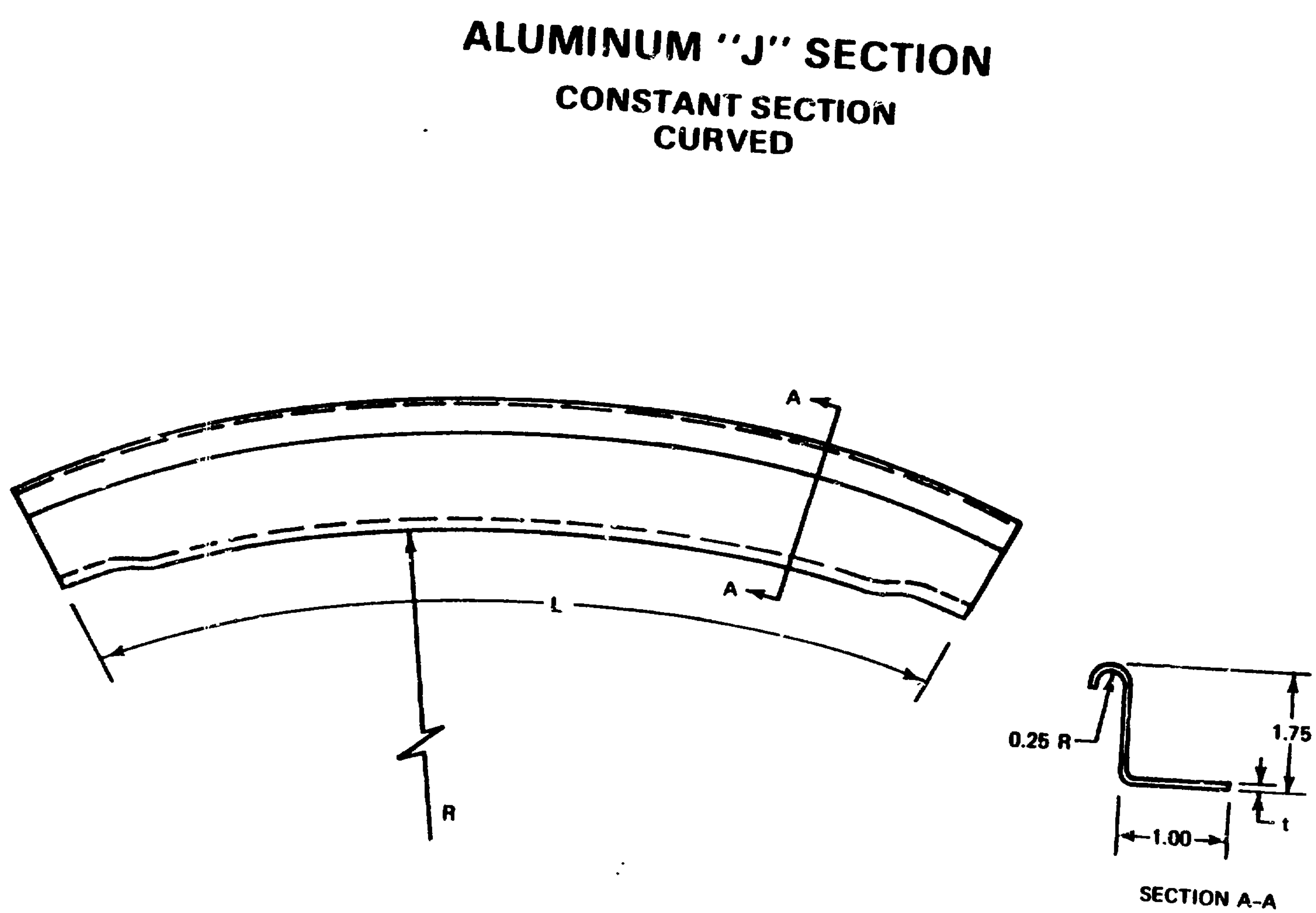


FIGURE 4.1-26. EXAMPLE OF SHEET METAL DISCRETE PART ANALYZED

MC/DG-A-5B

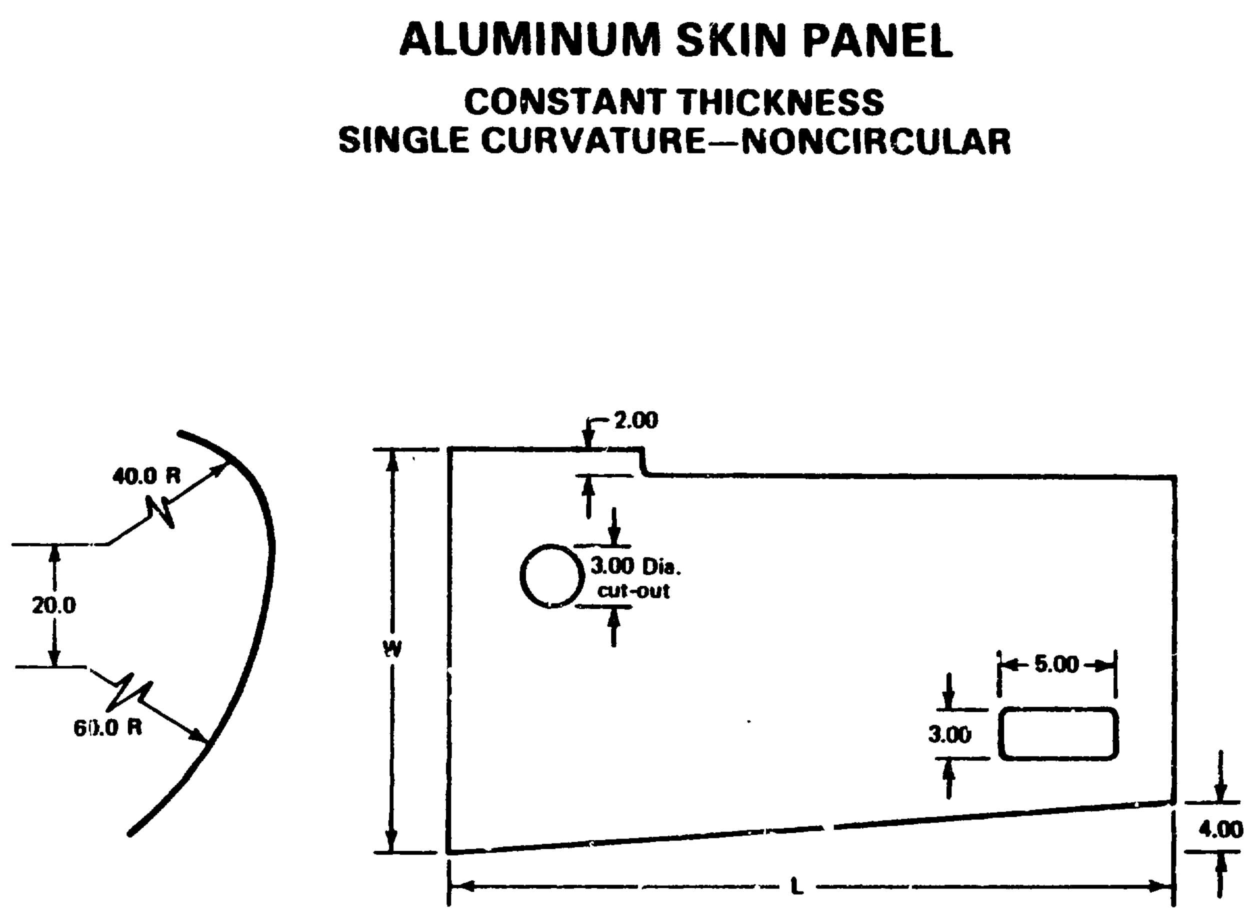


FIGURE 4.1-27. EXAMPLE OF SHEET METAL DISCRETE PART ANALYZED

MC/DG-A-9

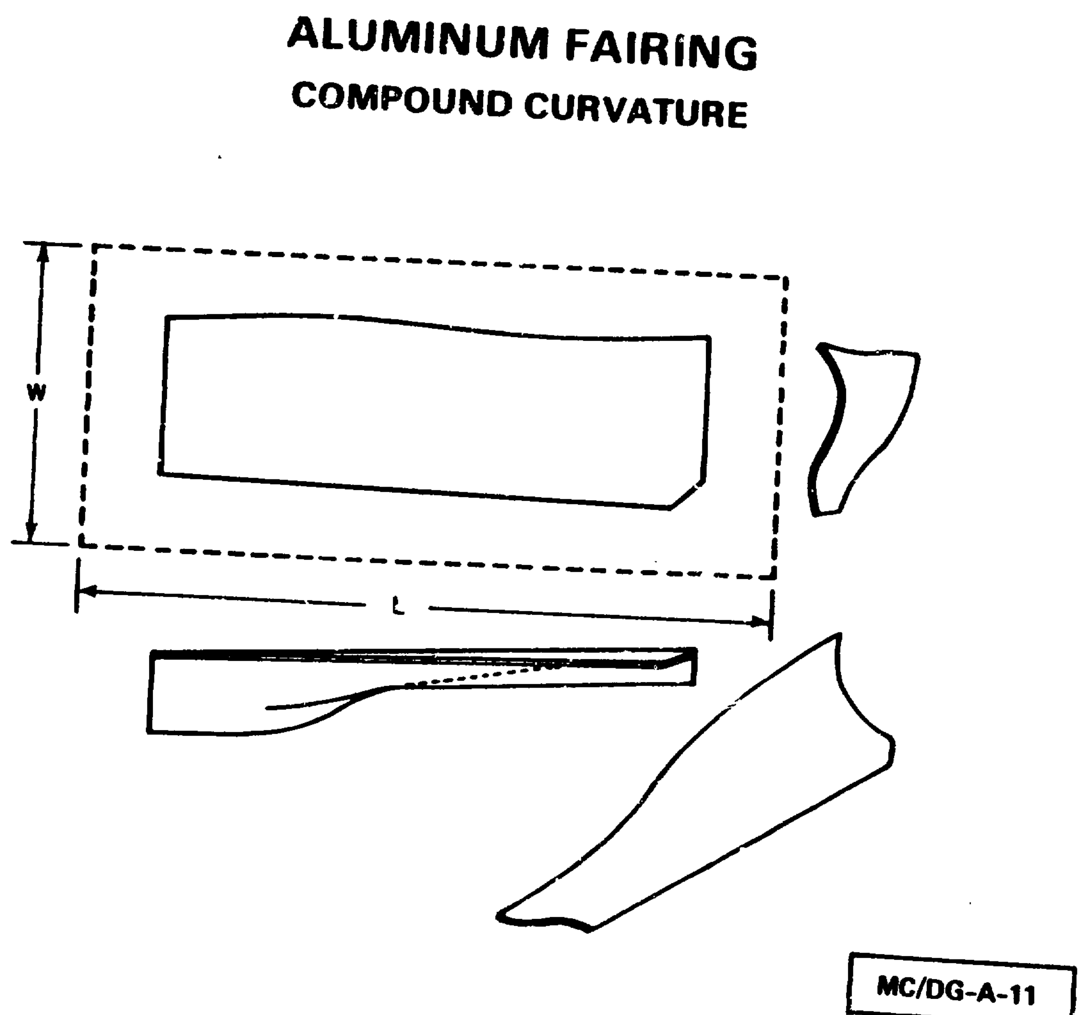


FIGURE 4.1-28. EXAMPLE OF SHEET METAL DISCRETE PART ANALYZED

ALUMINUM RIB

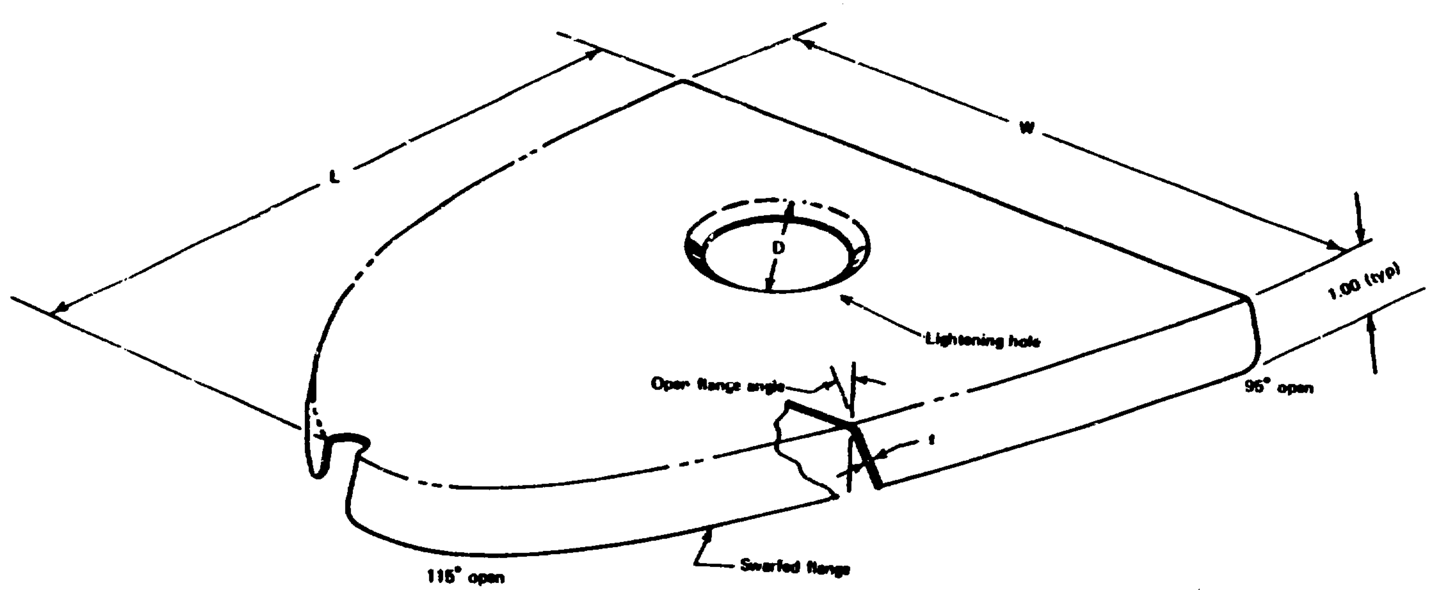


FIGURE 4.1-29. EXAMPLE OF SHEET METAL DISCRETE PART ANALYZED

MC/DG-A-12

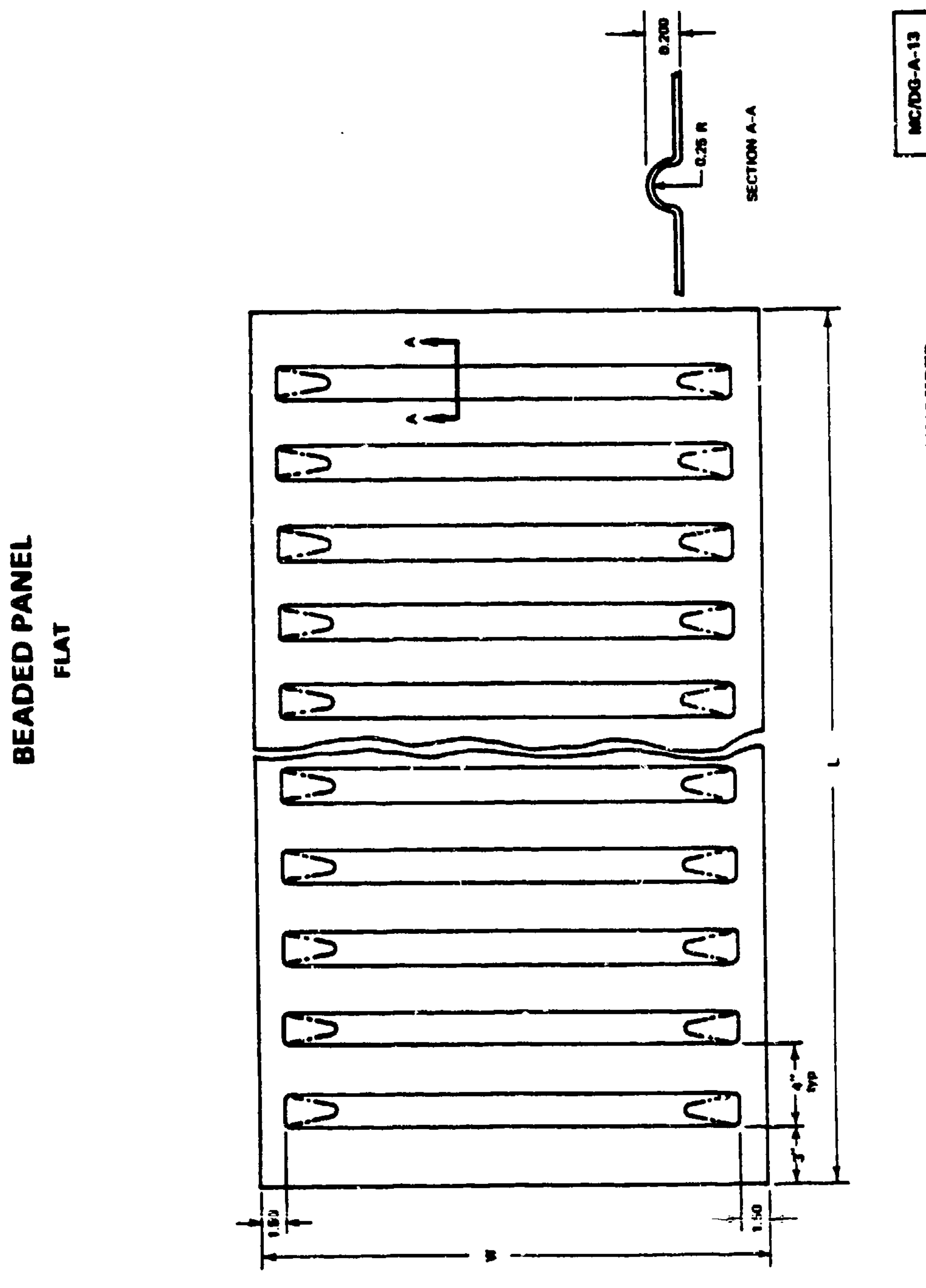


FIGURE 4.1-30. EXAMPLE OF SHEET METAL DISCRETE PART ANALYZED

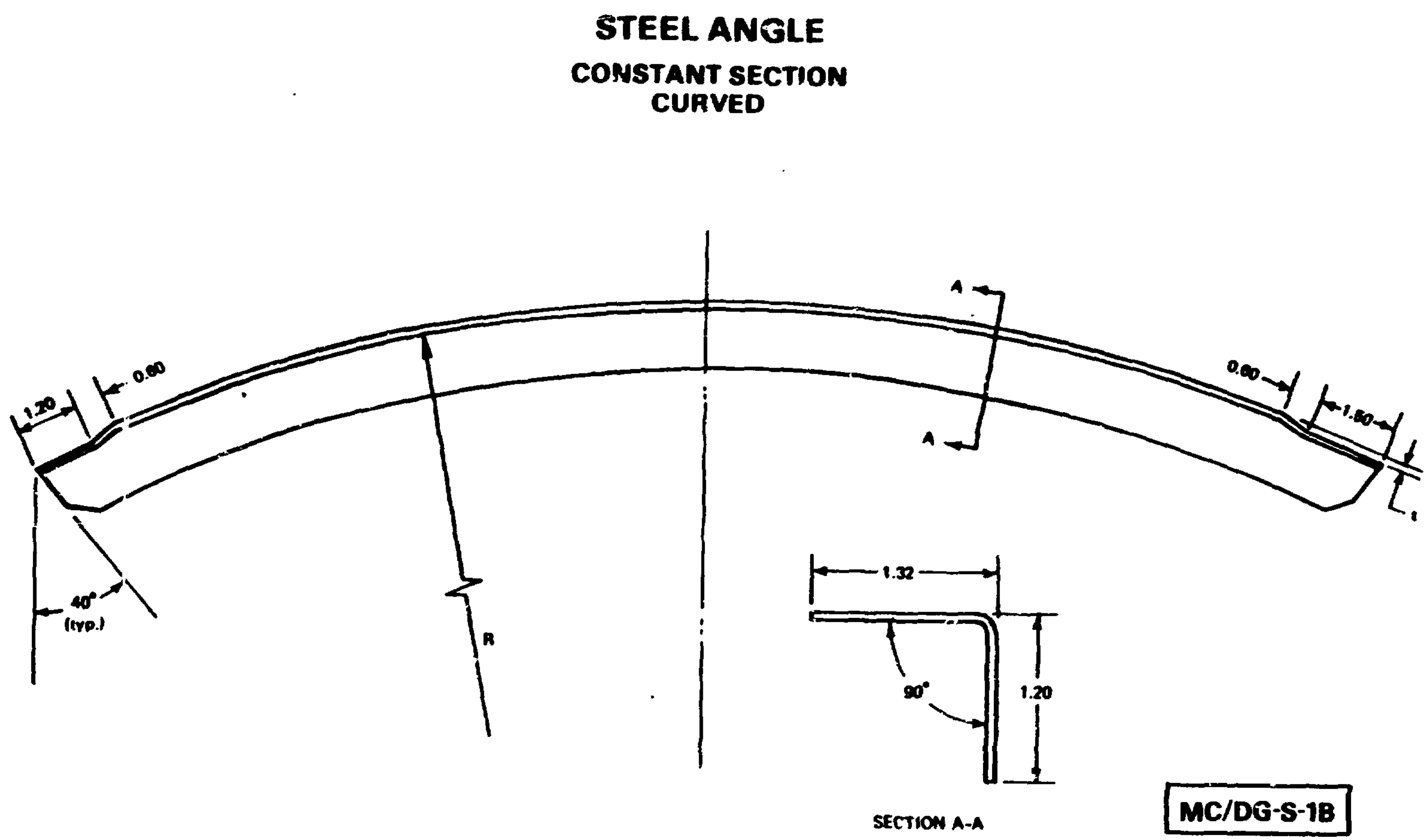


FIGURE 4.1-31. EXAMPLE OF SHEET METAL DISCRETE PART ANALYZED

MC/DG-S-2B

STEEL CHANNEL
CONSTANT SECTION
CURVED

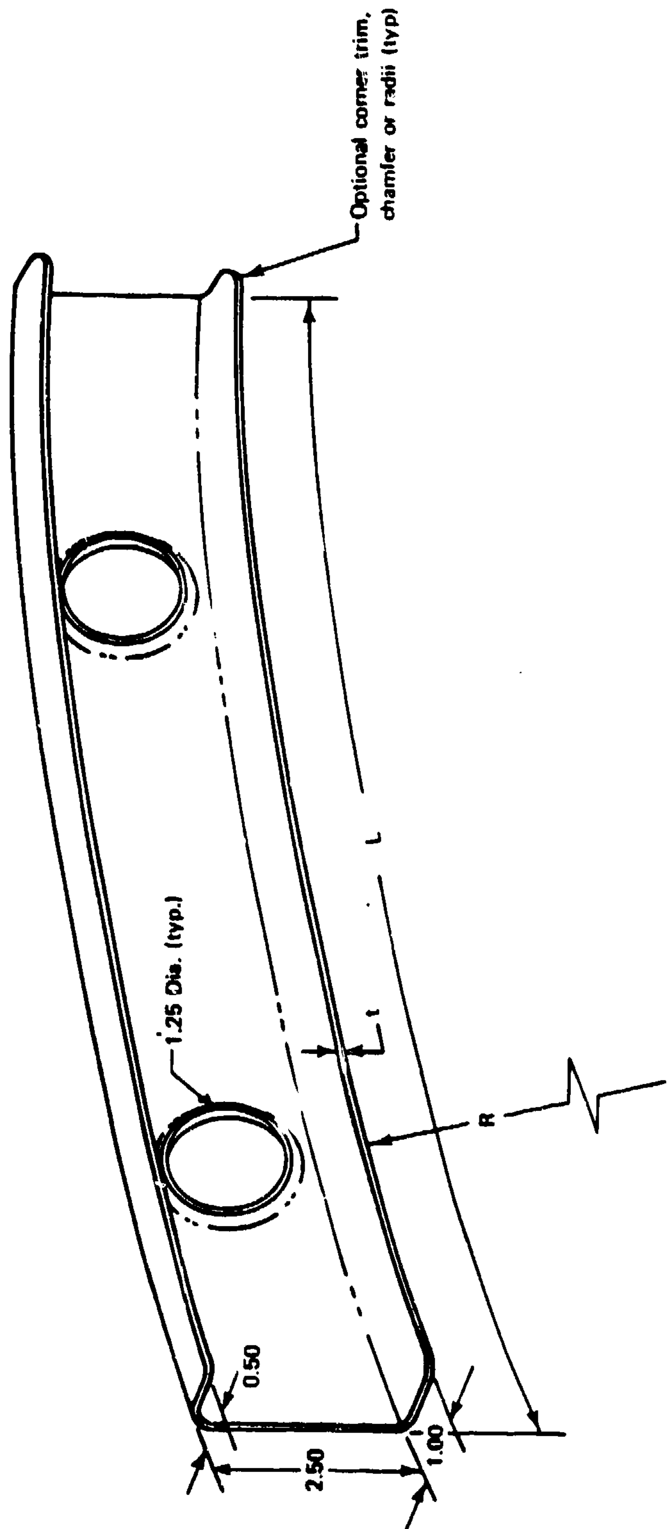


FIGURE 4.1-32. EXAMPLE OF SHEET METAL DISCRETE PART ANALYZED

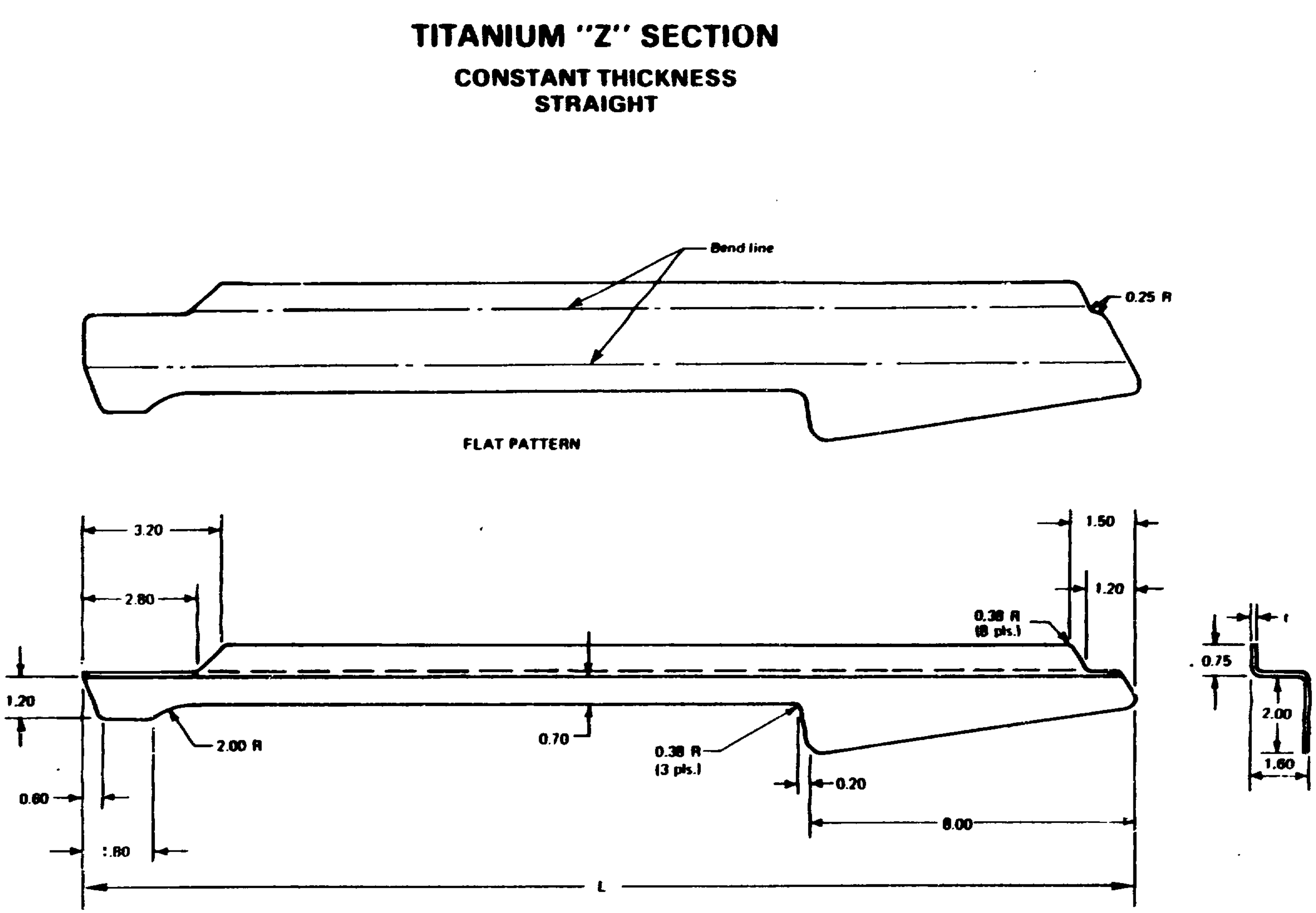


FIGURE 4.1-33. EXAMPLE OF SHEET METAL DISCRETE PART ANALYZED

MC/DG-T-3A

TITANIUM FRAME

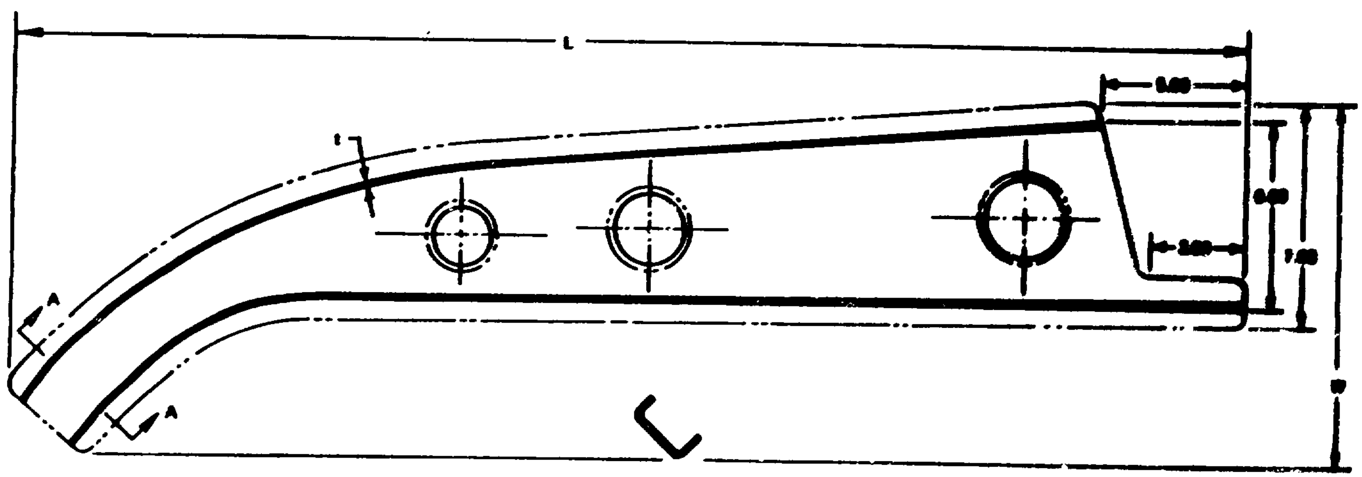


FIGURE 4.1-34. EXAMPLE OF SHEET METAL DISCRETE PART ANALYZED

4.1.5 Manufacturing Data for Sheet Metal

The formats on the following pages provide designer guidance for sheet metal aerospace discrete parts and also enable cost trade-off studies to be conducted.

4.1.5.1 Formats for Aluminum Sheet Metal Aercspace Discrete Parts Lowest Cost Process

The following conditions apply to utilizing the formats in this section:

(1) Review ground rules in section for considerations and limitations.

(2) Consider step occurring in recurring cost man-hours for lineal shapes, at length of 6 feet, due to requirement of two persons for certain manufacturing operations.

(3) Bend radius limitations for titanium:
- At room temperature forming $\geq$ 5t
- At elevated temperature forming $\geq$ 2t.

(4) Materials selection: The user of the MC/DG is cautioned with respect to the range of factors that can also play an important role, besides manufacturing cost, in the selection of an airframe material. The airframe design requirements may include:
- Elevated temperatures
- Operation in corrosive environments
- Higher acquisition costs might be acceptable due to lower operations and maintenance costs.

All factors must be carefully considered by the designer prior to selecting a material or design concept based on manufacturing cost.

(5) Review definitions in Section 2.2 "Terms and Abbreviations". However, important terminology used on most formats are:

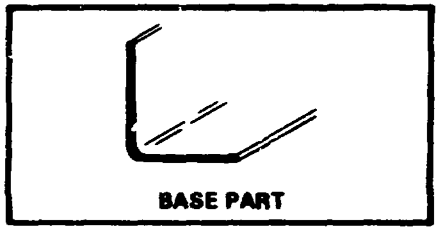
(a) Base Part: A detail part in its simplest form, i.e., without complexities such as heat treatment, cutouts, and joggles.

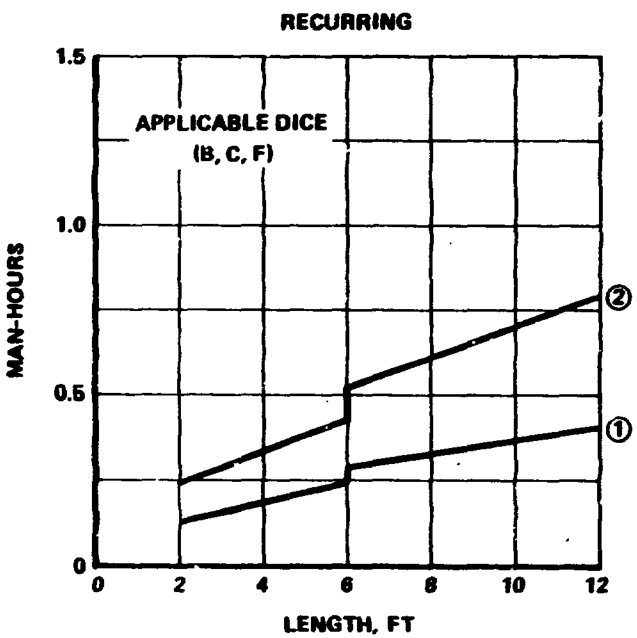
(b) Designer-Influenced Cost Elements (DICE): Includes joggles, cutouts, lightening holes, and special tolerances that add cost to the base part configuration. These additional costs are due to the increased fabrication operations and tooling required over the standard manufacturing method (SMM) for the base part.

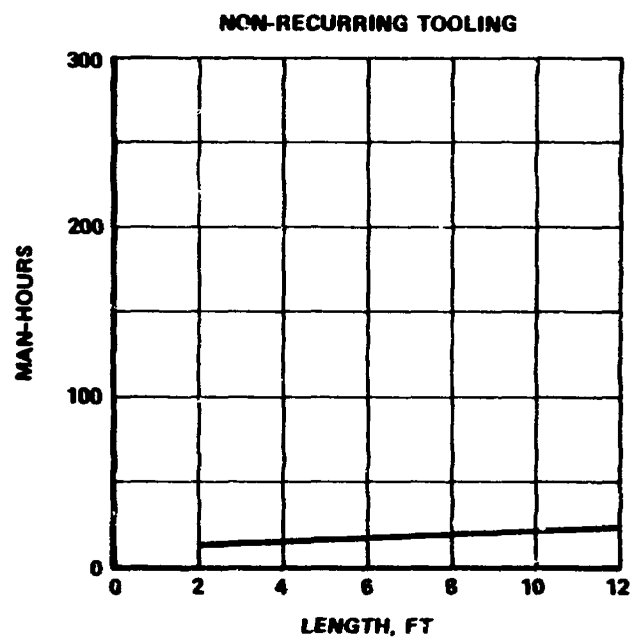
(c) Detail or Discrete Parts: A distinct airframe structural part which may incorporate complexities, e.g., a base part plus DICE, ready for assembly to perform its required function in the airframe.

ALUMINUM ANGLE, STRAIGHT MEMBER, LOWEST COST PROCESS

BRAKE FORM





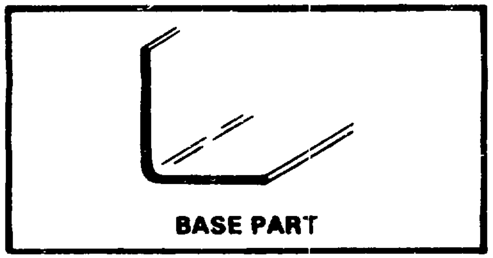


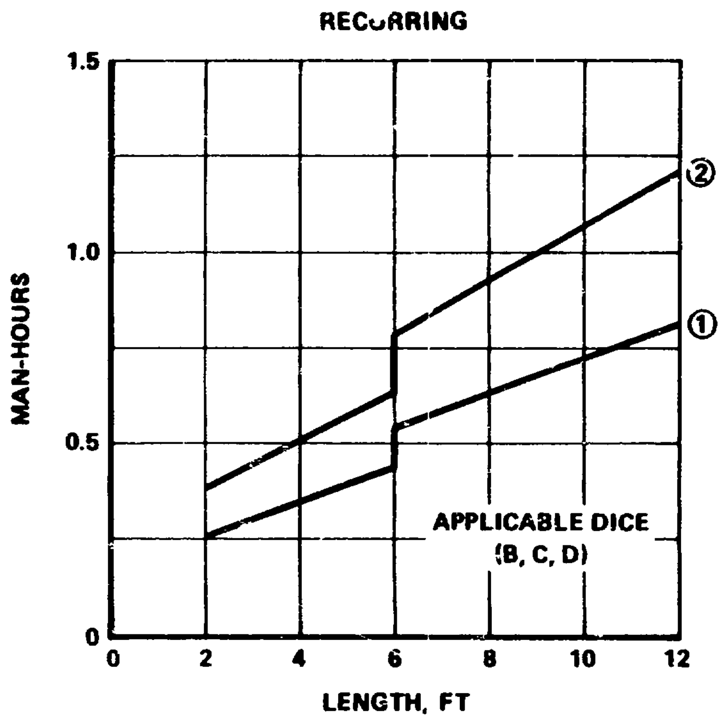
(1) PART FORMED IN T3 CONDITION (NO SOLUTION HEAT TREAT), MINIMUM BEND RADIUS = 3.5t
(2) PART FORMED IN "O" OR "W" CONDITION; T62 FINAL TEMPER; MINIMUM BEND RADIUS = 1.5t

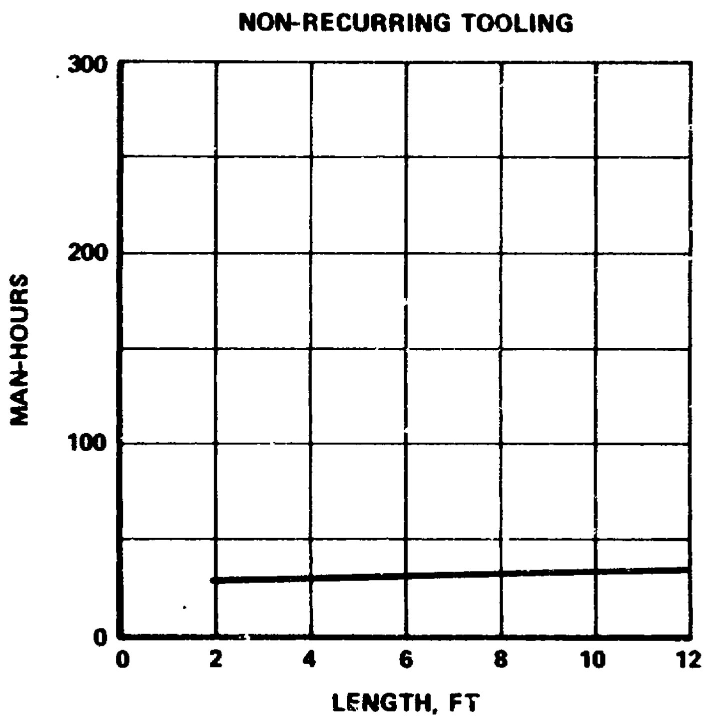
CED—A-1

ALUMINUM ANGLE, CYLINDRICALLY CONTOURED MEMBER, LOWEST COST PROCESS

BRAKE/ROLL





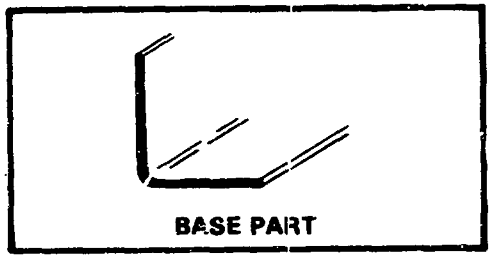


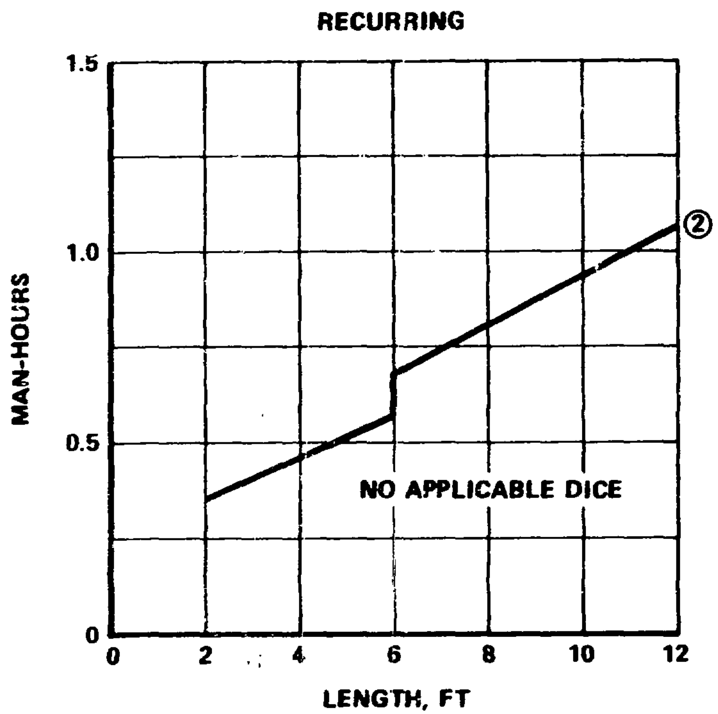
(1) PART FORMED IN T3 CONDITION (NO SOLUTION HEAT TREAT), MINIMUM BEND RADIUS = 3.5t
(2) PART FORMED IN "O" OR "W" CONDITION; T62 FINAL TEMPER; MINIMUM BEND RADIUS = 1.5t

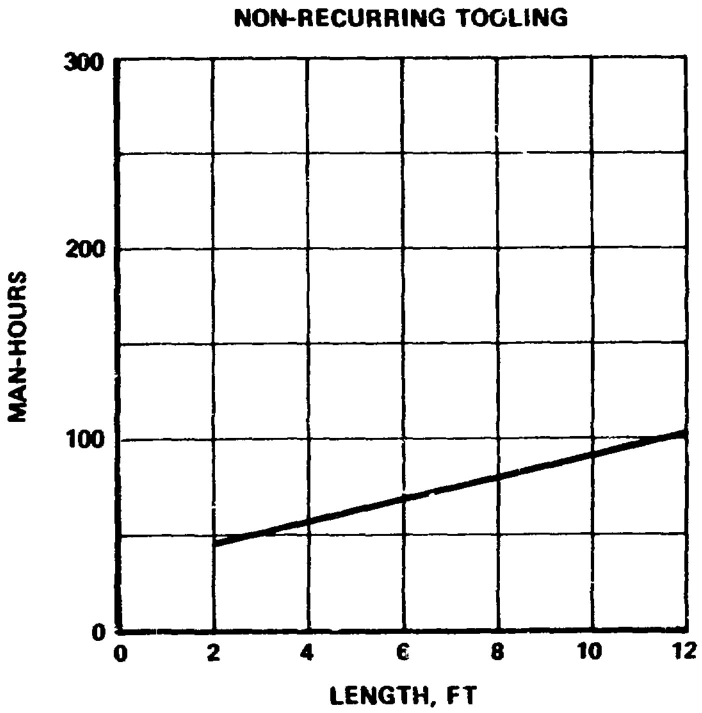
CED—A-2

ALUMINUM ANGLE, NON-CYLINDRICALLY CONTOURED MEMBER,* LOWEST COST PROCESS

RUBBER PRESS







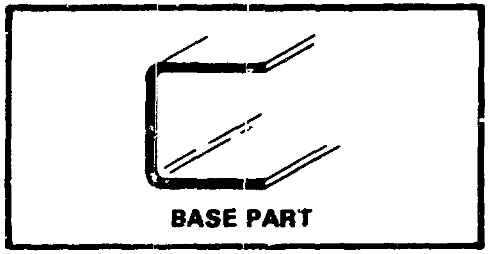
*NO REVERSE CURVES

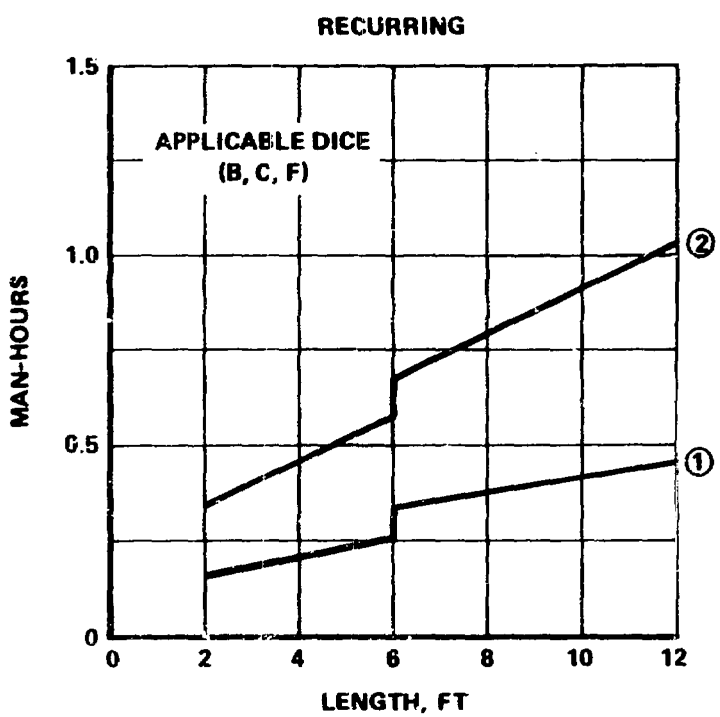
(2) PART FORMED IN "O" OR "W" CONDITION; T62 FINAL TEMPER; MINIMUM BEND RADIUS = 1.5t

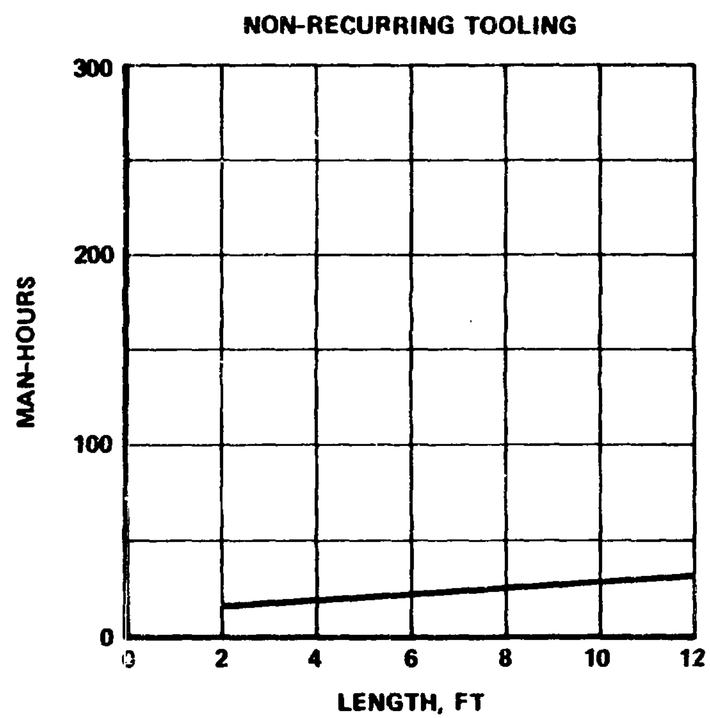
CED—A-3

ALUMINUM CHANNEL, STRAIGHT MEMBER, LOWEST COST PROCESS

BRAKE FORM





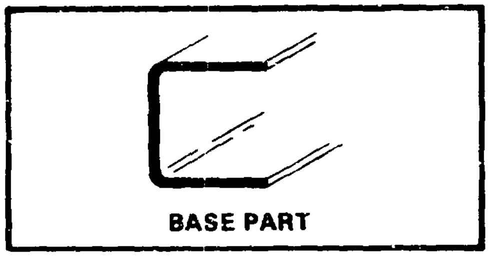


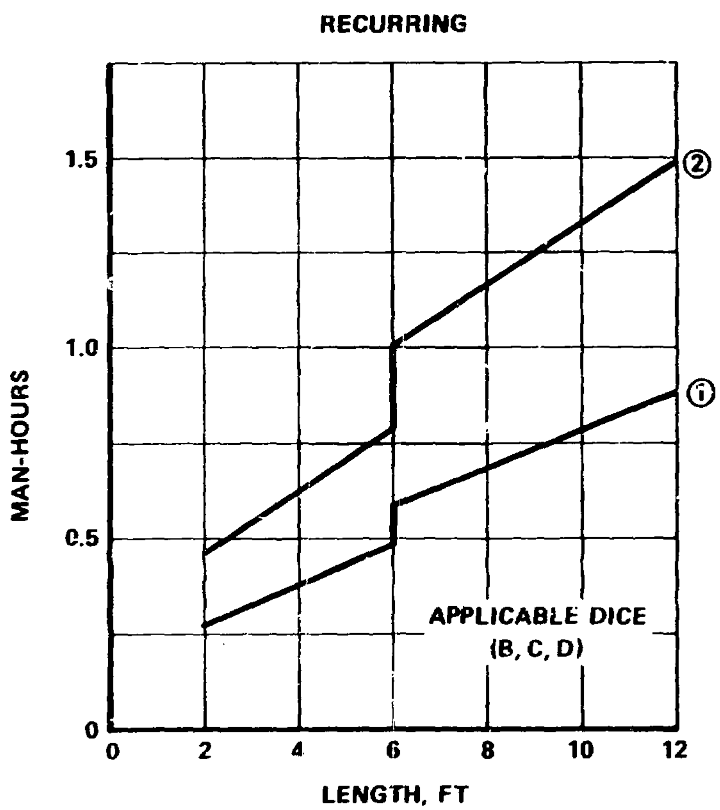
(1) PART FORMED IN T3 CONDITION (NO SOLUTION HEAT TREAT); MINIMUM BEND RADIUS = 3.5t
(2) PART FORMED IN "O" OR "W" CONDITION; T62 FINAL TEMPER; MINIMUM BEND RADIUS = 1.5t

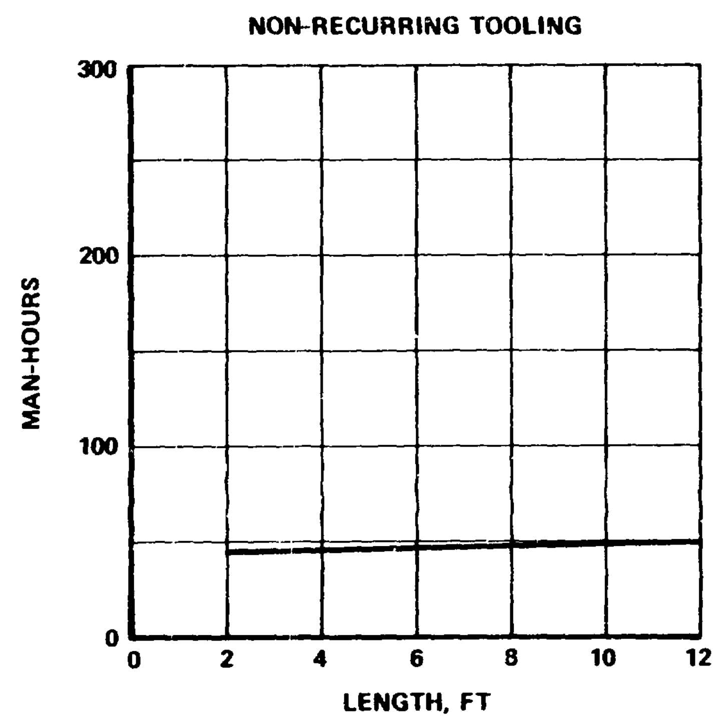
CED—A-4

ALUMINUM CHANNEL, CYLINDRICALLY CONTOURED MEMBER, LOWEST COST PROCESS

BRAKE/ROLL





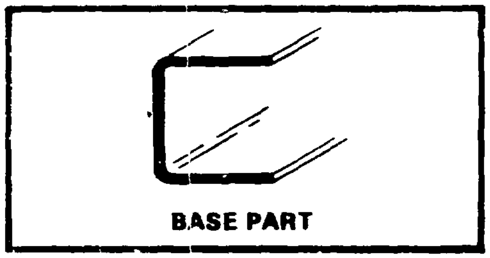


(1) PART FORMED IN T3 CONDITION (NO SOLUTION HEAT TREAT); MINIMUM BEND RADIUS = 3.5t
(2) PART FORMED IN "O" OR "W" CONDITION; T62 FINAL TEMPER; MINIMUM BEND RADIUS = 1.5t

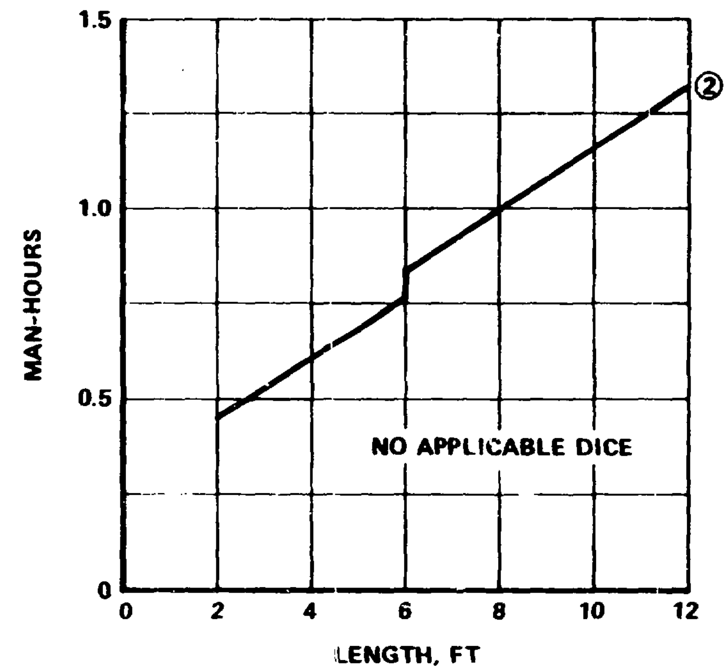
CED—A-5

ALUMINUM CHANNEL, NON-CYLINDRICALLY CONTOURED MEMBER,* LOWEST COST PROCESS

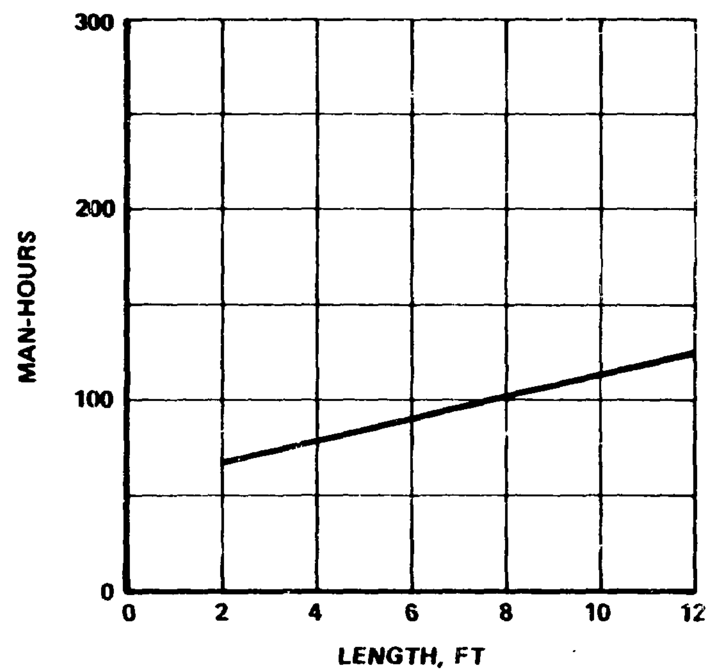
RUBBER PRESS



RECURRING



NON-RECURRING TOOLING



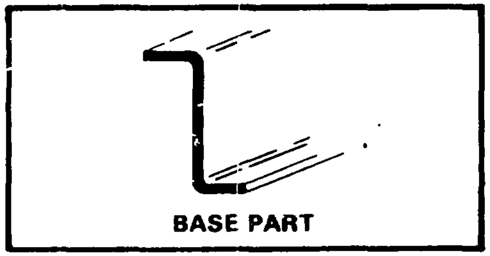
*NO REVERSE CURVES

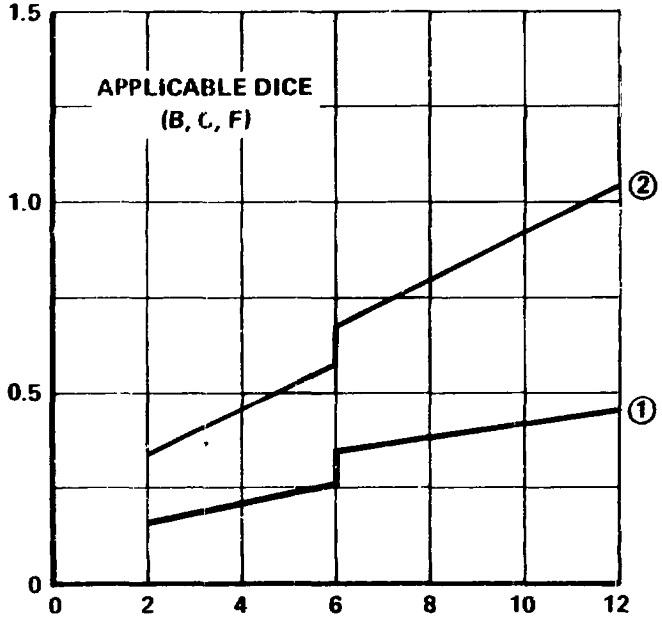
(2) PART FORMED IN "O" OR "W" CONDITION; T62 FINAL TEMPER; MINIMUM BEND RADIUS = 1.5t

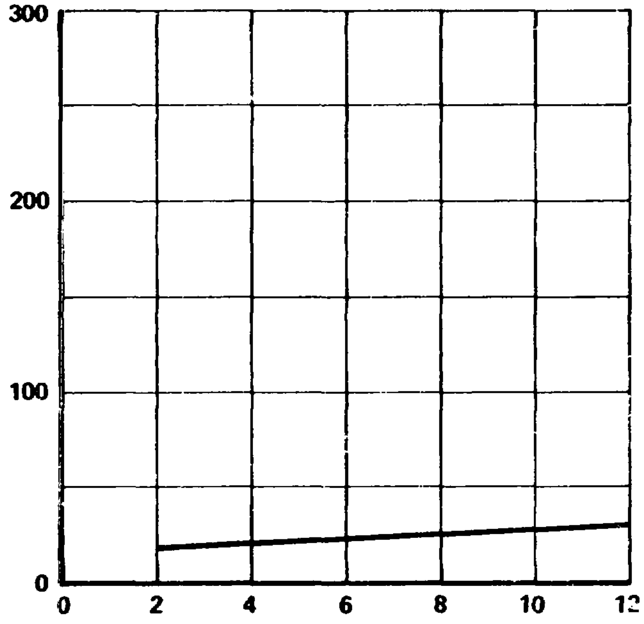
CED—A-6

ALUMINUM ZEE, STRAIGHT MEMBER, LOWEST COST PROCESS

BRAKE FORM





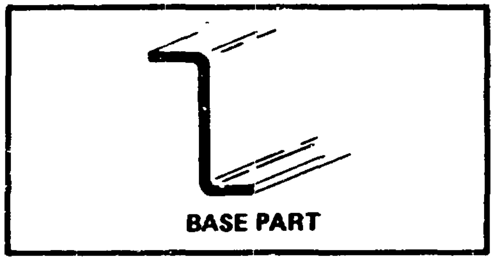


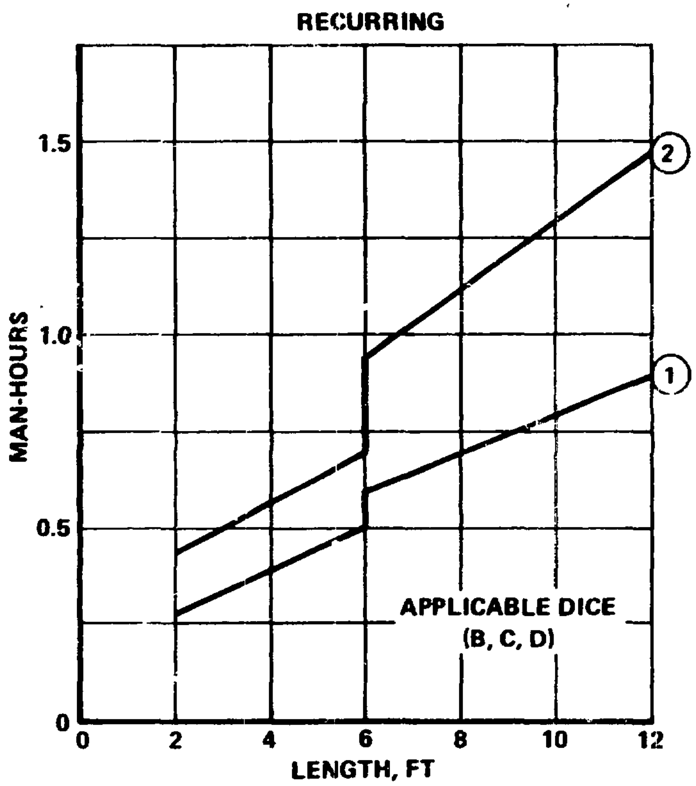
(1) PART FORMED IN T3 CONDITION (NO SOLUTION HEAT TREAT); MINIMUM BEND RADIUS = 3.5t
(2) PART FORMED IN "O" OR "W" CONDITION; T62 FINAL TEMPER; MINIMUM BEND RADIUS = 1.5t

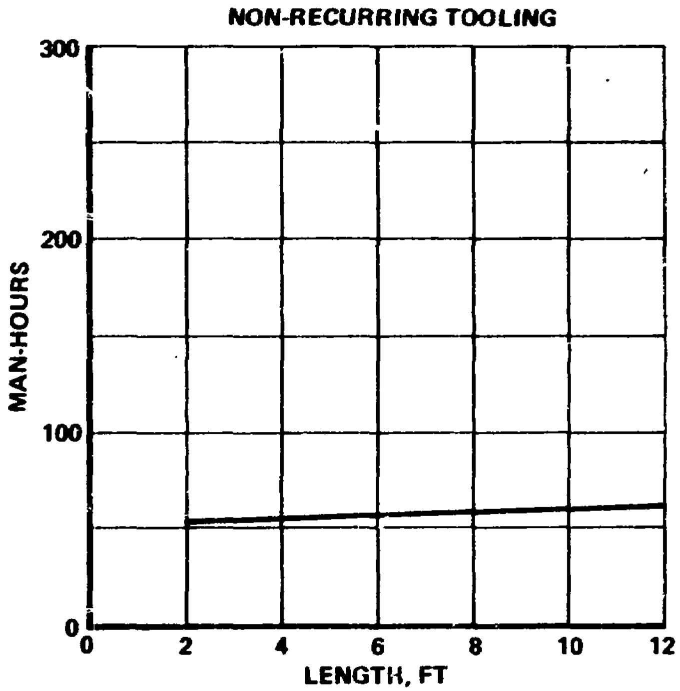
CED—A-7

ALUMINUM ZEE, CYLINDRICALLY CONTOURED MEMBER, LOWEST COST PROCESS

BRAKE/ROLL

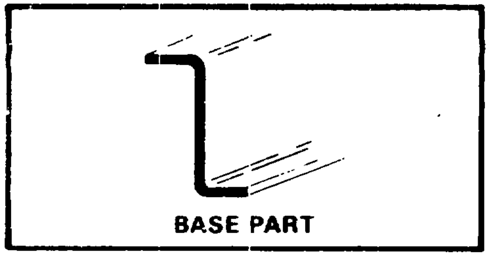






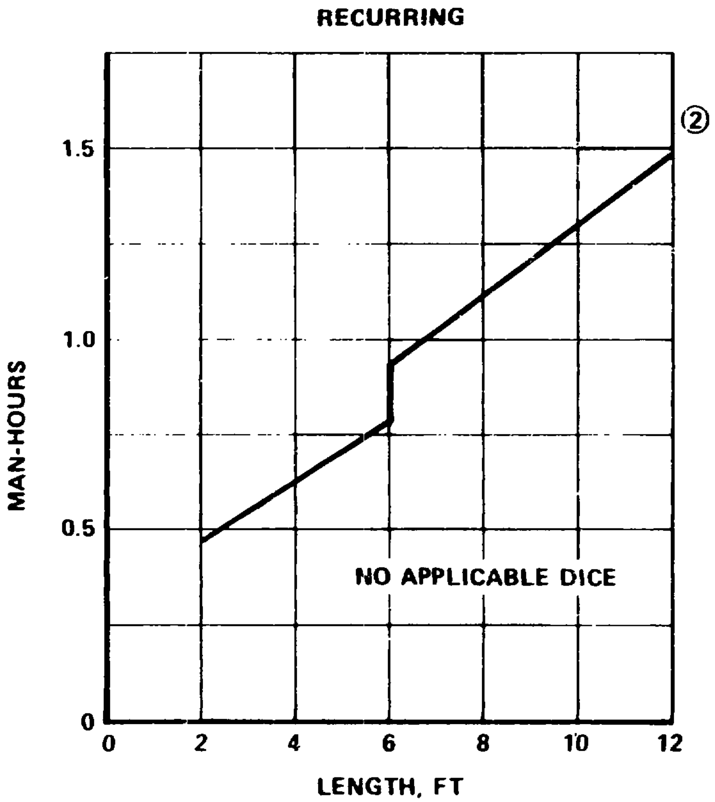
(1) PART FORMED IN T3 CONDITION (NO SOLUTION HEAT TREAT); MINIMUM BEND RADIUS = 3.5t
(2) PART FORMED IN "O" OR "W" CONDITION: T62 FINAL TEMPER; MINIMUM BEND RADIUS = 1.5t

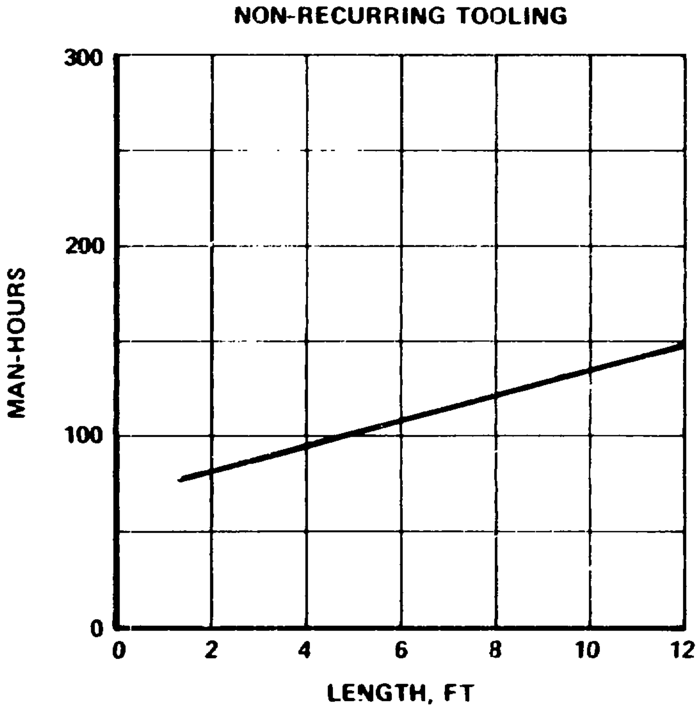
CED—A-8



ALUMINUM ZEE, NON-CYLINDRICALLY CONTOURED MEMBER,* LOWEST COST PROCESS

RUBBER PRESS



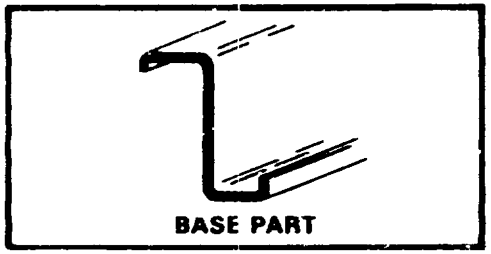


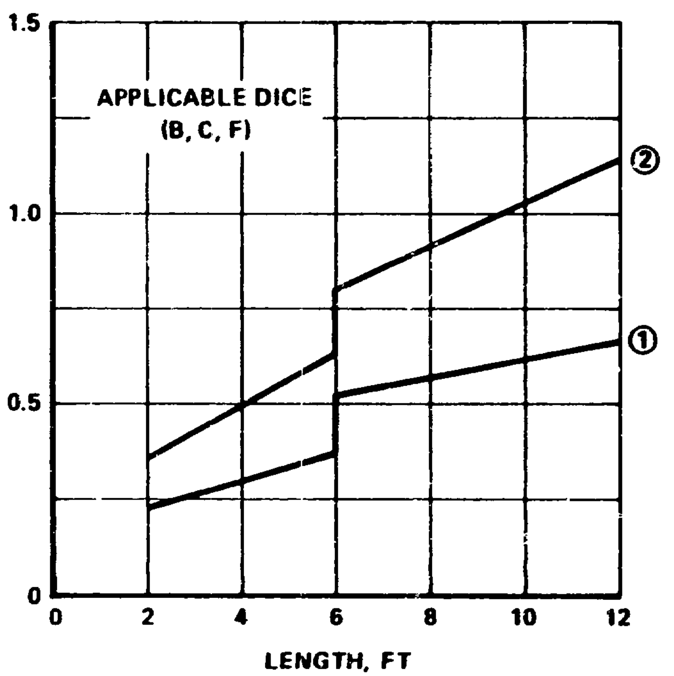
*NO REVERSE CURVES
(2) PART FORMED IN "O" OR "W" CONDITION; T62 FINAL TEMPER; MINIMUM BEND RADIUS = 1.5t

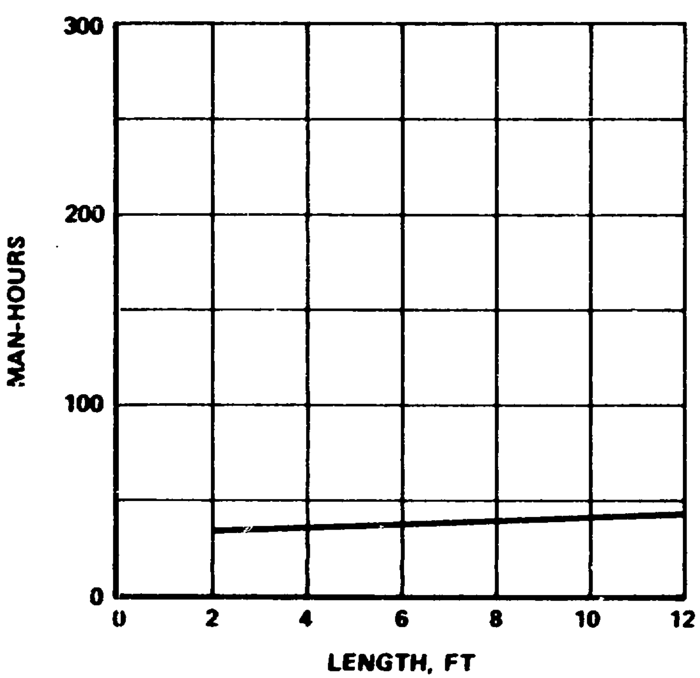
CED—A-9

ALUMINUM LIPPED ZEE, STRAIGHT MEMBER, LOWEST COST PROCESS

BRAKE FORM





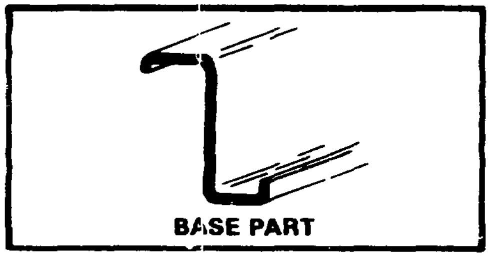


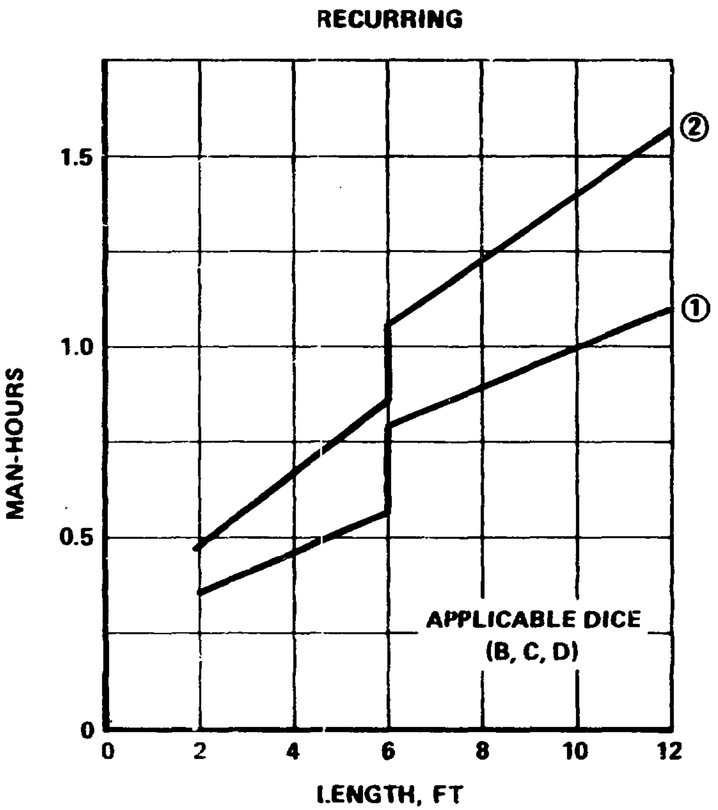
(1) PART FORMED IN T3 CONDITION (NO SOLUTION HEAT TREAT); MINIMUM BEND RADIUS = 3.5t
(2) PART FORMED IN "O" OR "W" CONDITION; T62 FINAL TEMPER; MINIMUM BEND RADIUS = 1.5t

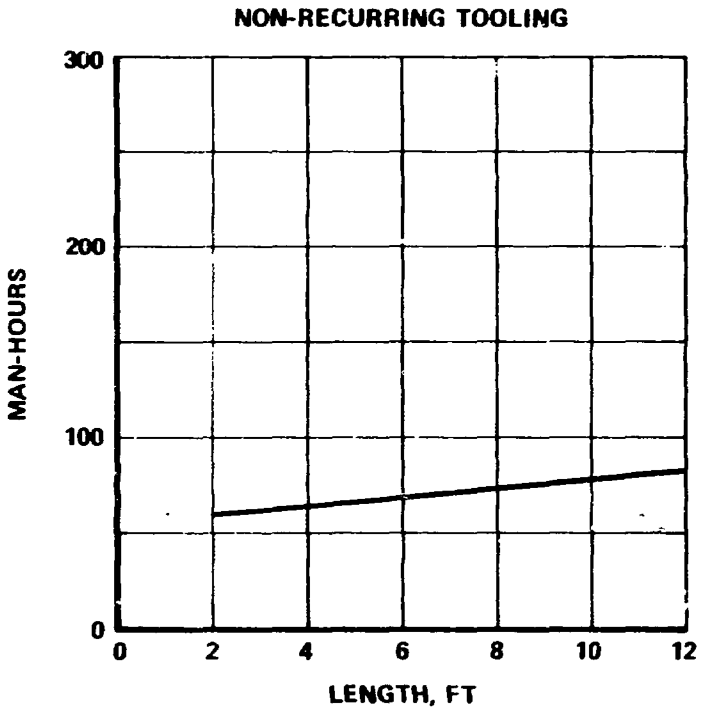
CED—A-10

ALUMINUM LIPPED ZEE, CYLINDRICALLY CONTOURED MEMBER, LOWEST COST PROCESS

BRAKE/ROLL





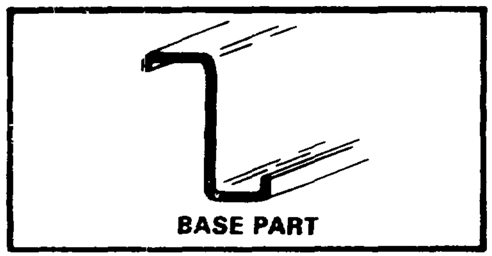


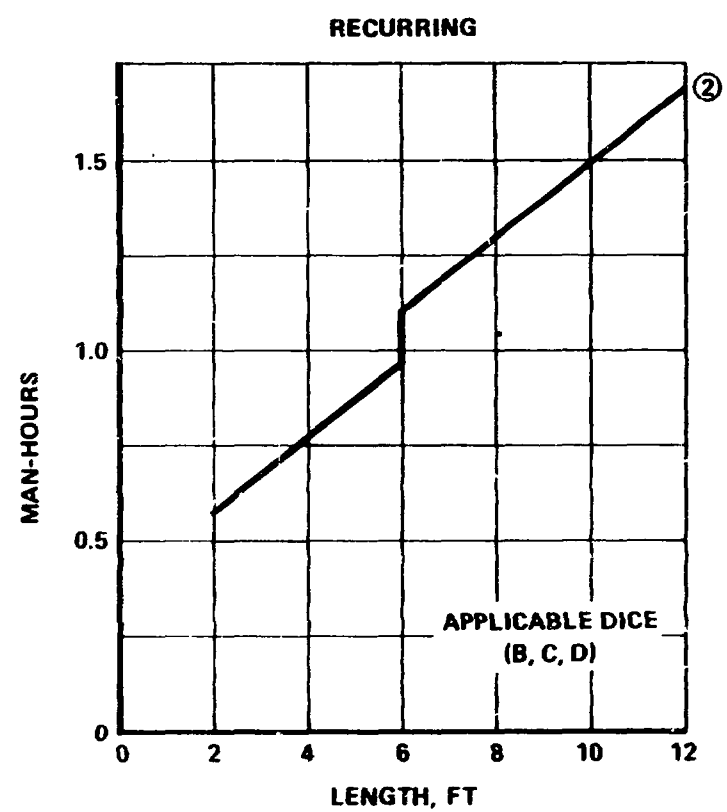
(1) PART FORMED IN T3 CONDITION (NO SOLUTION HEAT TREAT); MINIMUM BEND RADIUS = 3.5t
(2) PART FORMED IN "O" OR "W" CONDITION; T62 FINAL TEMPER; MINIMUM BEND RADIUS = 1.5t

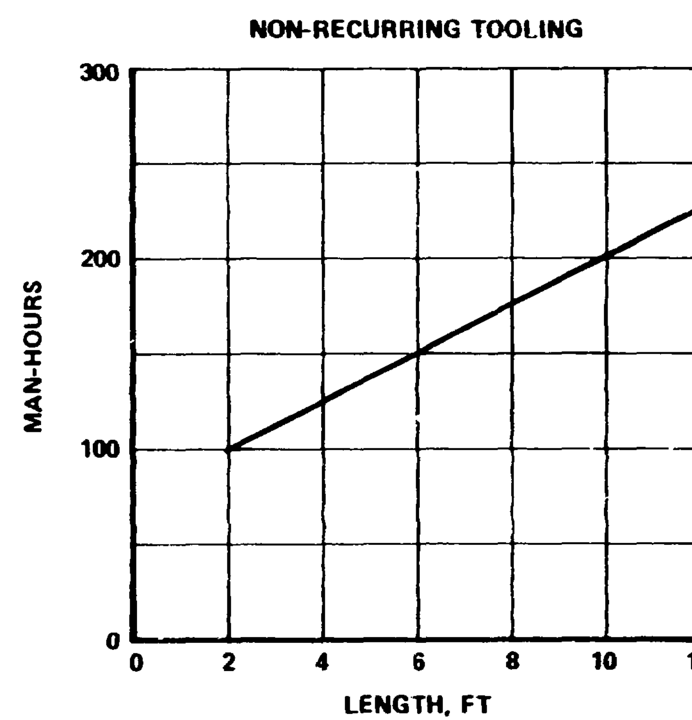
CED—A-11

ALUMINUM LIPPED ZEE, NON-CYLINDRICALLY CONTOURED MEMBER,* LOWEST COST PROCESS

BRAKE/STRETCH







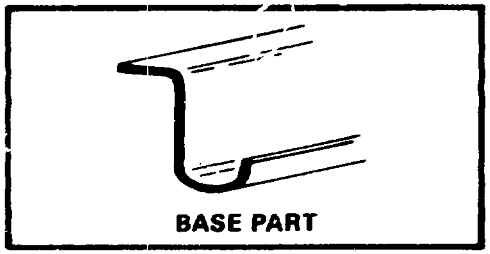
*NO REVERSE CURVES

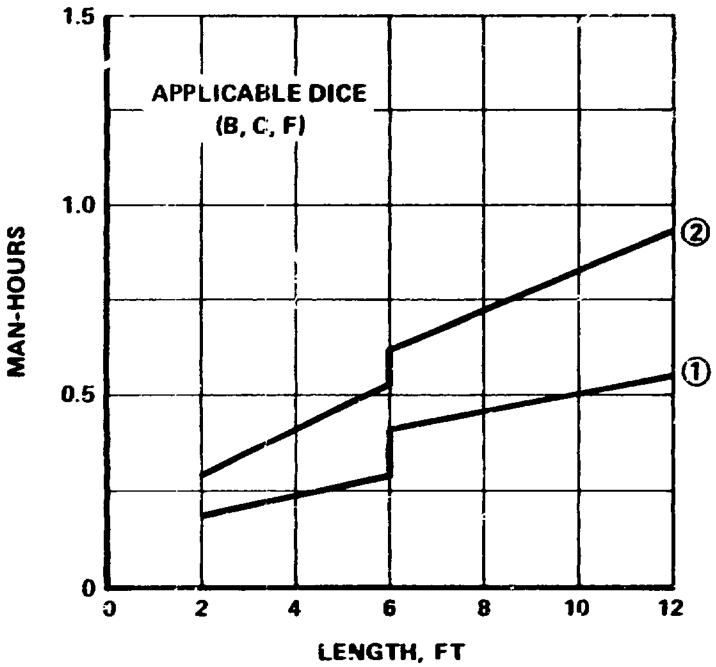
(2) PART FORMED IN "O" OR "W" CONDITION; T62 FINAL TEMPER; MINIMUM BEND RADIUS = 1.5t

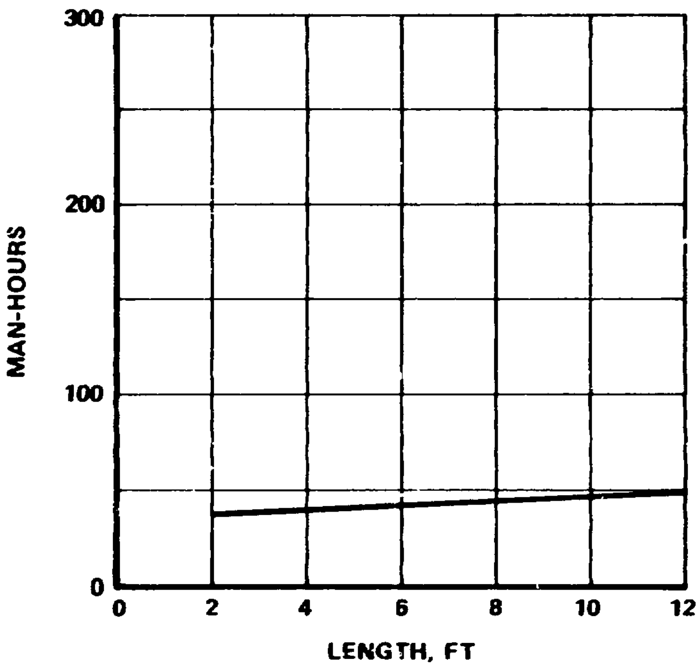
CED—A-12

ALUMINUM J, STRAIGHT MEMBER, LOWEST COST PROCESS

BRAKE FORM





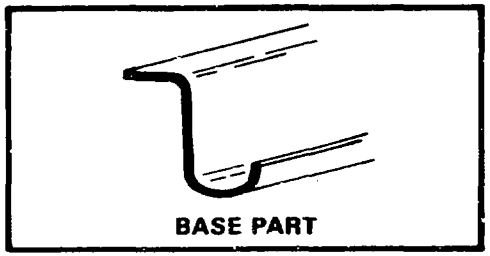


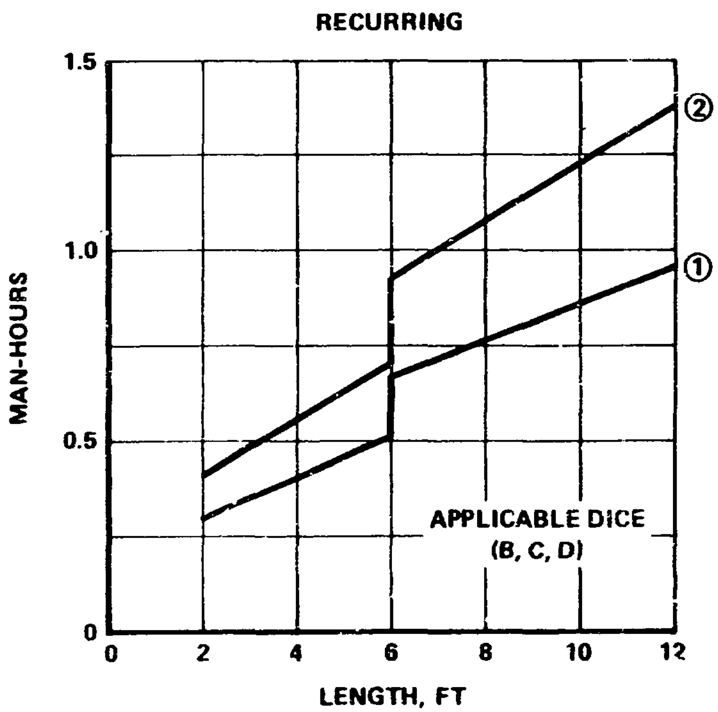
(1) PART FORMED IN T3 CONDITION (NO SOLUTION HEAT TREAT), MINIMUM BEND RADIUS = 3.5t
(2) PART FORMED IN "O" OR "W" CONDITION; T62 FINAL TEMPER; MINIMUM BEND RADIUS = 1.5t

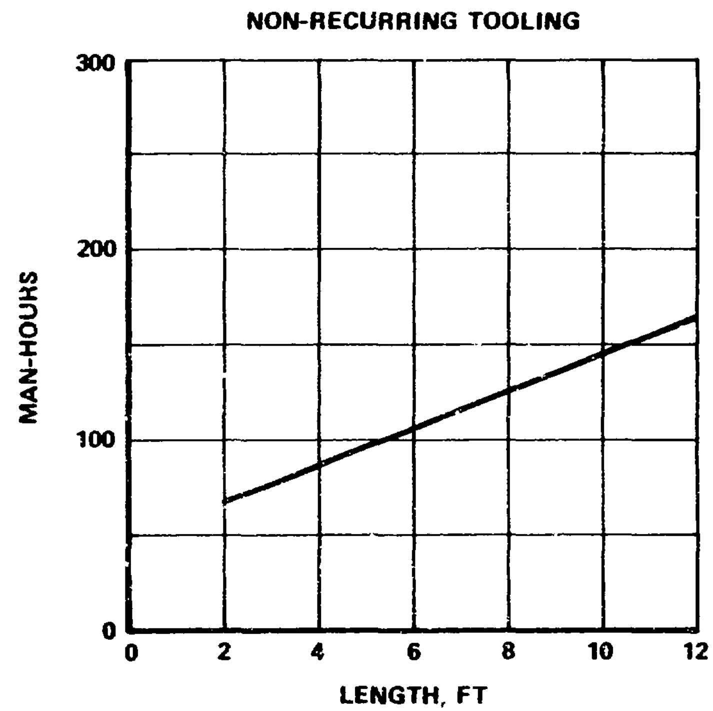
CED—A-13

ALUMINUM J, CYLINDRICALLY CONTOURED MEMBER, LOWEST COST PROCESS

BRAKE/ROLL





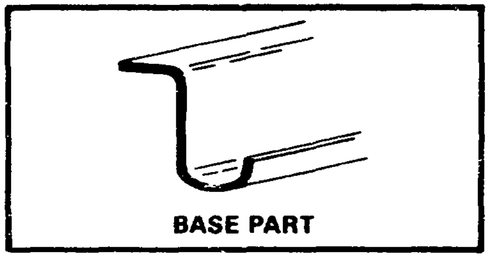


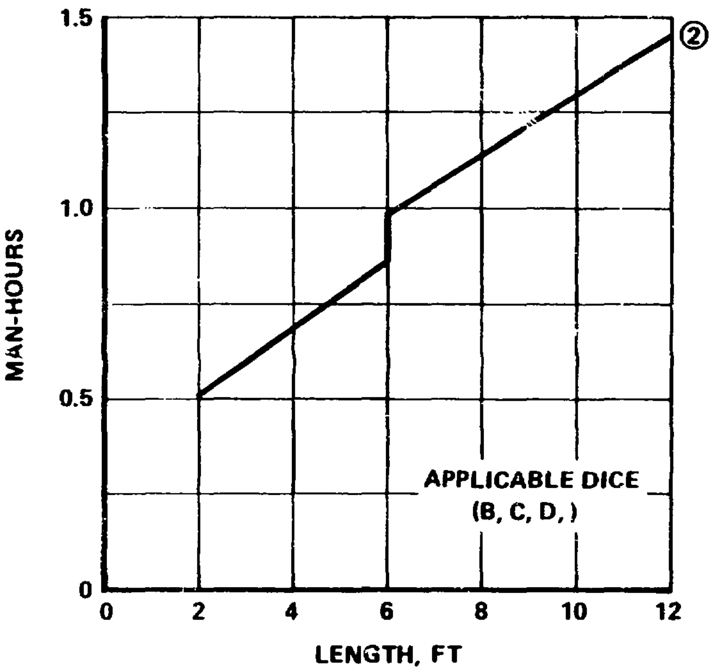
(1) PART FORMED IN T3 CONDITION (NO SOLUTION HEAT TREAT), MINIMUM BEND RADIUS = 3.5t
(2) PART FORMED IN "O" OR "W" CONDITION; T62 FINAL TEMPER; MINIMUM BEND RADIUS = 1.5t

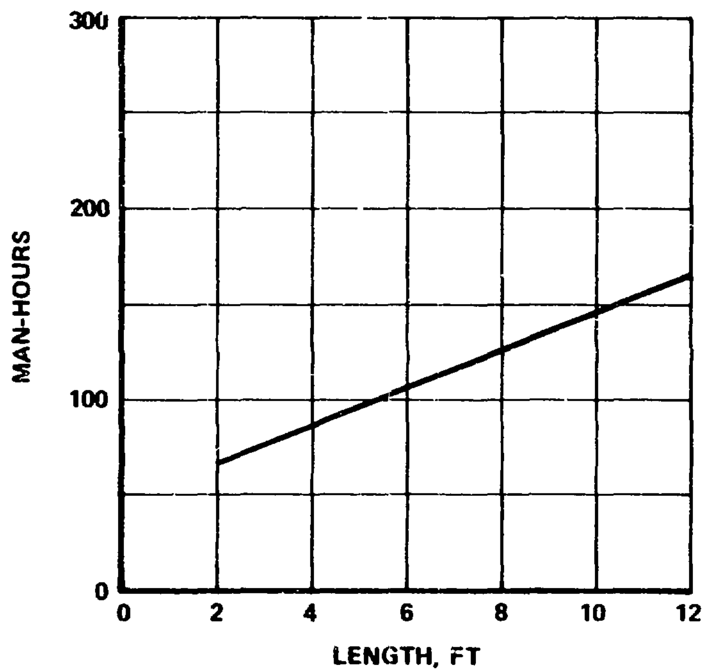
CED—A-14

ALUMINUM J, NON-CYLINDRICALLY CONTOURED MEMBER,* LOWEST COST PROCESS

BRAKE/STRETCH







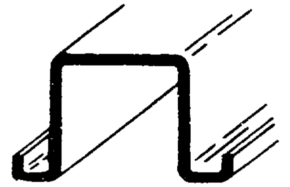
*NO REVERSE CURVES

(2) PART FORMED IN "O" OR "W" CONDITION; T62 FINAL TEMPER; MINIMUM BEND RADIUS = 1.5t

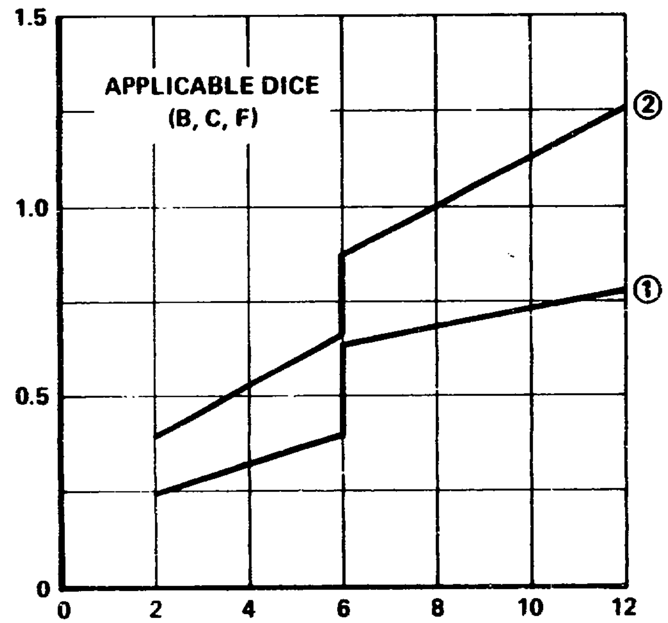
CED—A-15

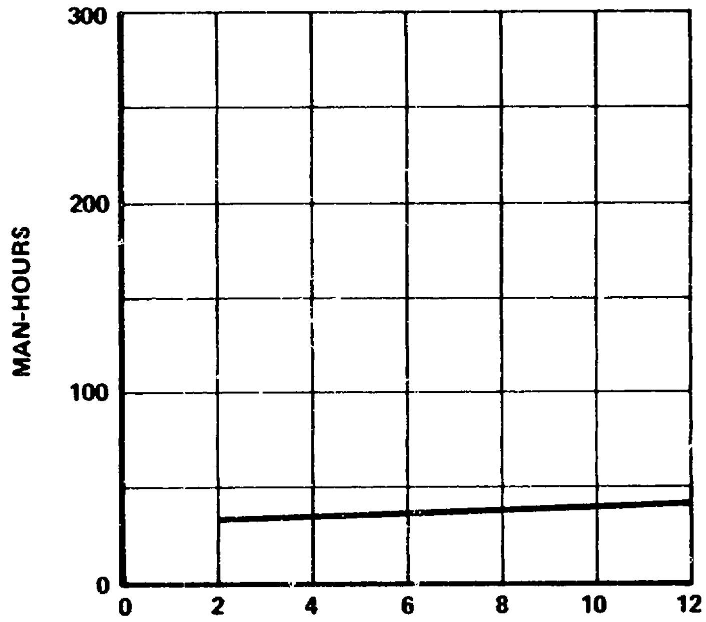
ALUMINUM LIPPED HAT, STRAIGHT MEMBER, LOWEST COST PROCESS

BRAKE FORM



BASE PART

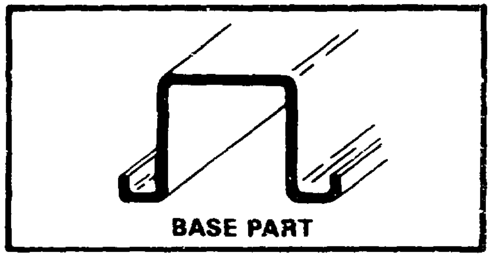


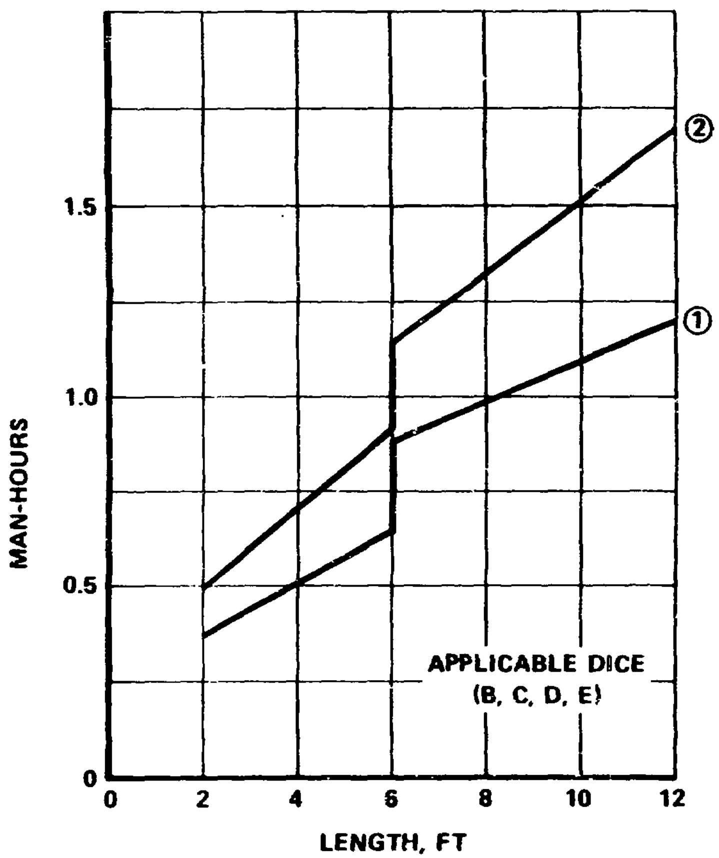


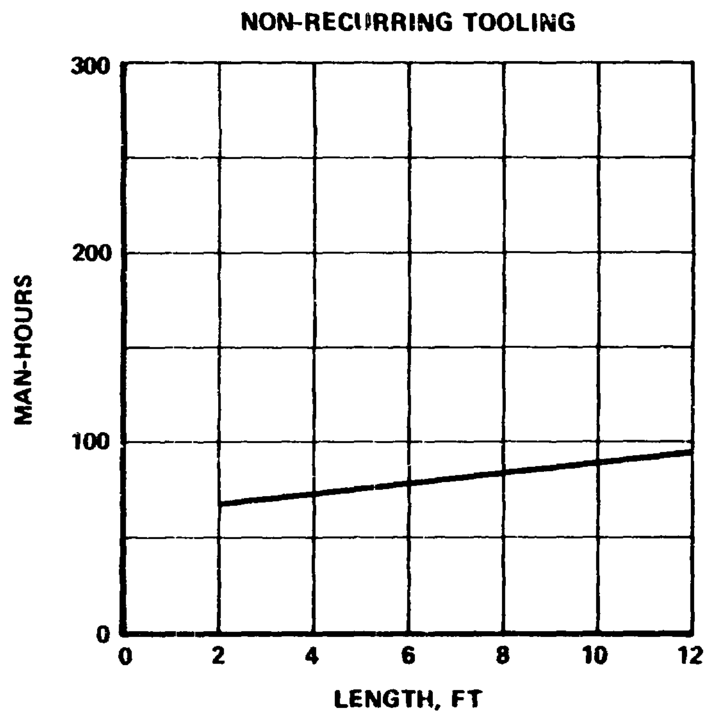
(1) PART FORMED IN T3 CONDITION (NO SOLUTION HEAT TREAT), MINIMUM BEND RADIUS = 3.5t
(2) PART FORMED IN "O" OR "W" CONDITION; T62 FINAL TEMPER; MINIMUM BEND RADIUS = 1.5t

CED—A-16

ALUMINUM LIPPED HAT, CYLINDRICALLY CONTOURED MEMBER, LOWEST COST PROCESS BRAKE/ROLL





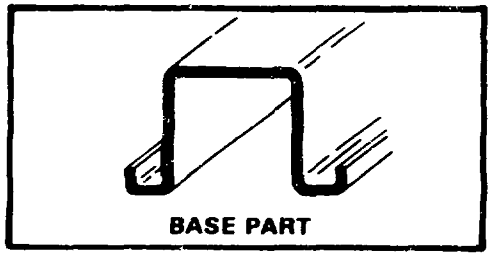


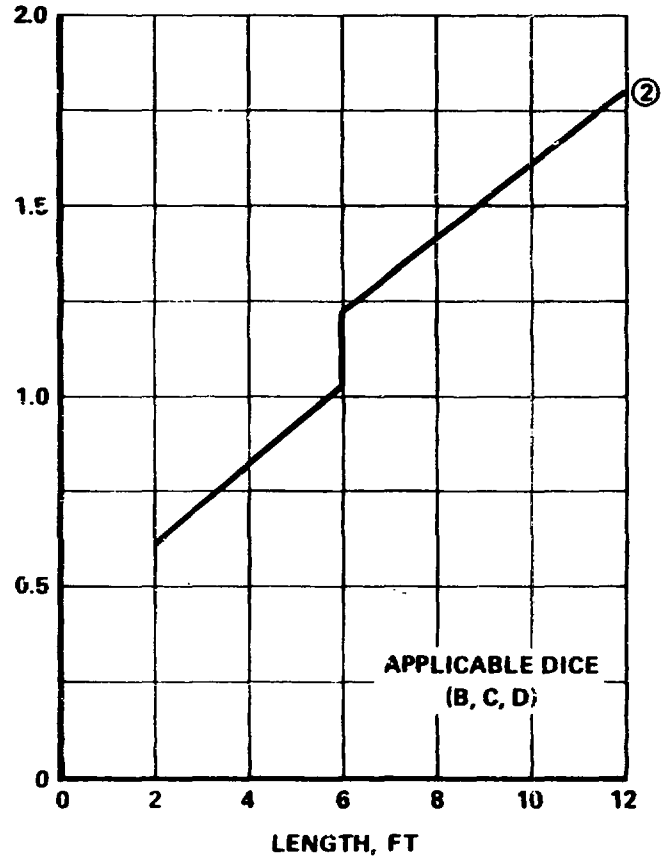
(1) PART FORMED IN T3 CONDITION (NO SOLUTION HEAT TREAT), MINIMUM BEND RADIUS = 3.5t
(2) PART FORMED IN "O" OR "W" CONDITION; T62 FINAL TEMPER; MINIMUM BEND RADIUS = 1.5t

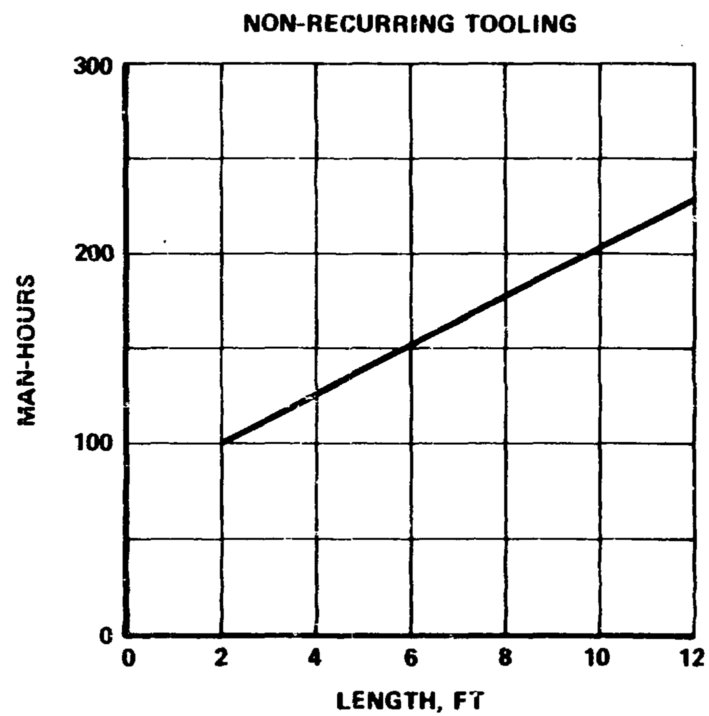
CED—A-17

ALUMINUM LIPPED HAT, NON-CYLINDRICALLY CONTOURED MEMBER,* LOWEST COST PROCESS

BRAKE/STRETCH





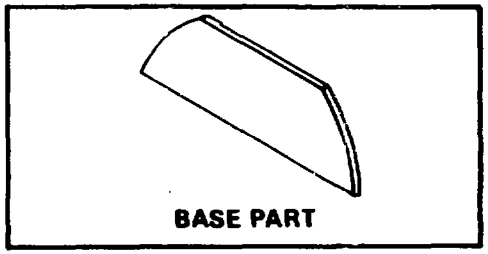


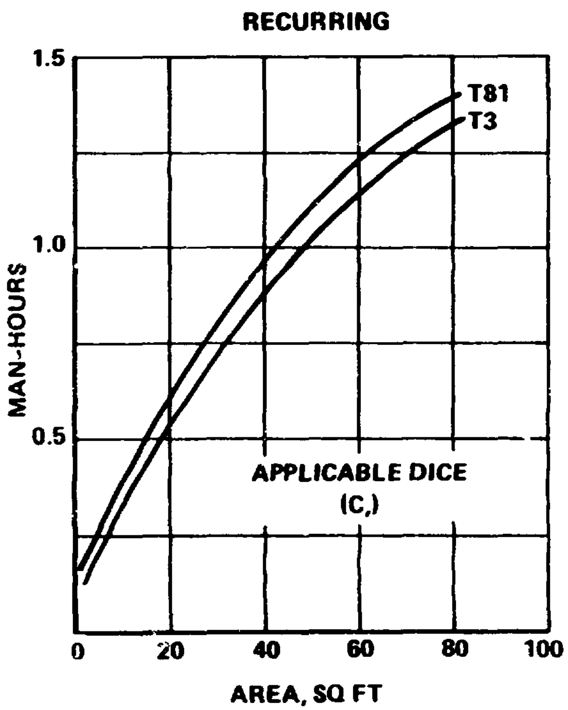
*NO REVERSE CURVES

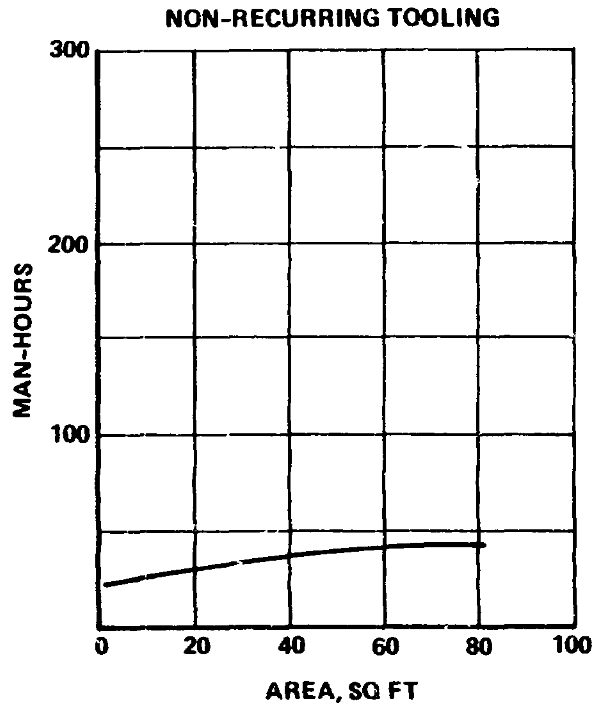
(2) PART FORMED IN "O" OR "W" CONDITION; T62 FINAL TEMPER; MINIMUM BEND RADIUS = 1.5t

CED—A-18

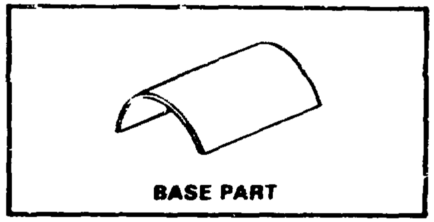
ALUMINUM FLAT SHEET, LOWEST COST PROCESS (ROUTING APPLICABLE ONLY)





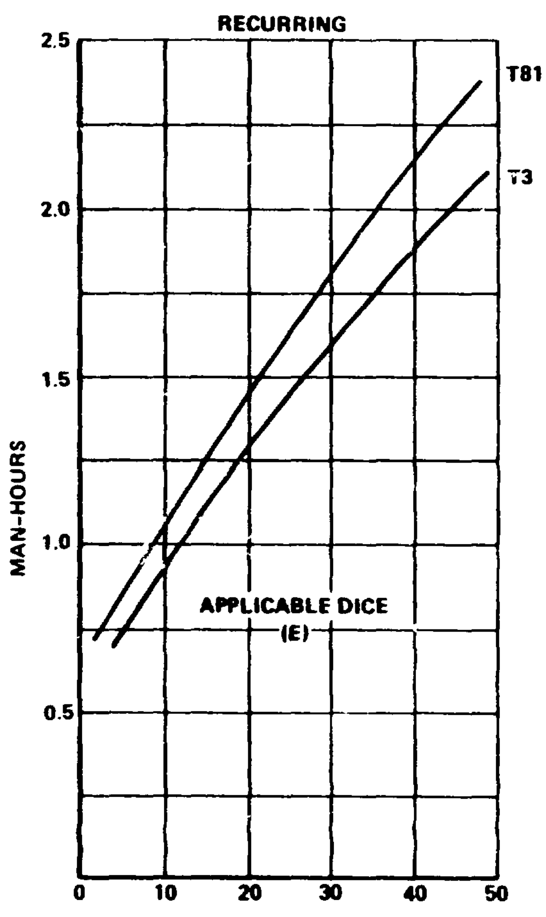


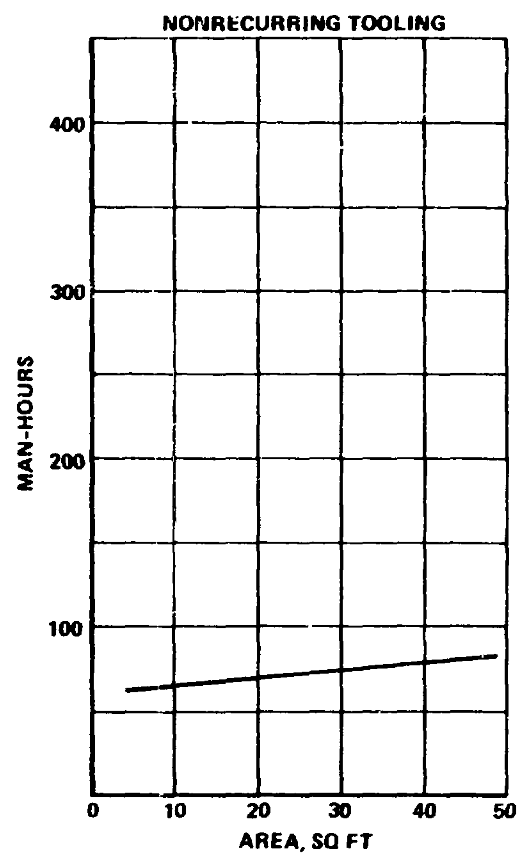
CED—A-19



ALUMINUM CYLINDRICAL CURVATURE SKIN, LOWEST COST PROCESS FARNHAM ROLL

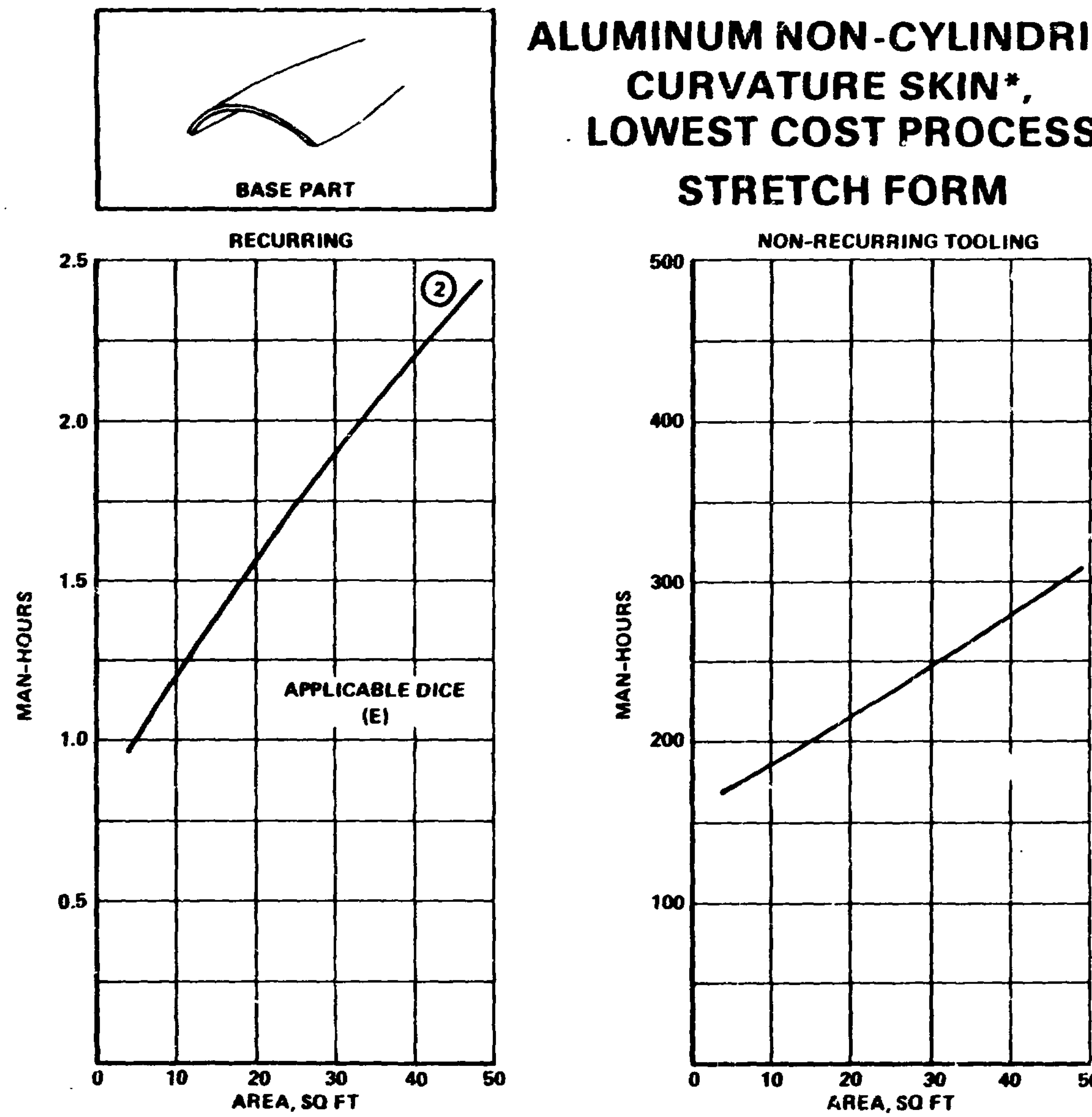
(PERIMETER TRIM INCLUDED)





CED—A-20

ALUMINUM NON-CYLINDRICAL CURVATURE SKIN*, LOWEST COST PROCESS
STRETCH FORM

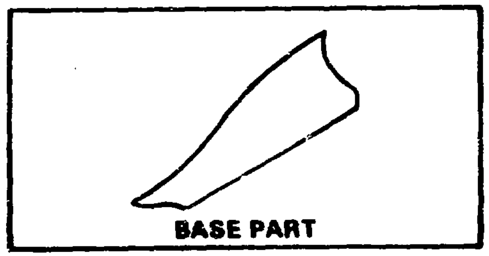


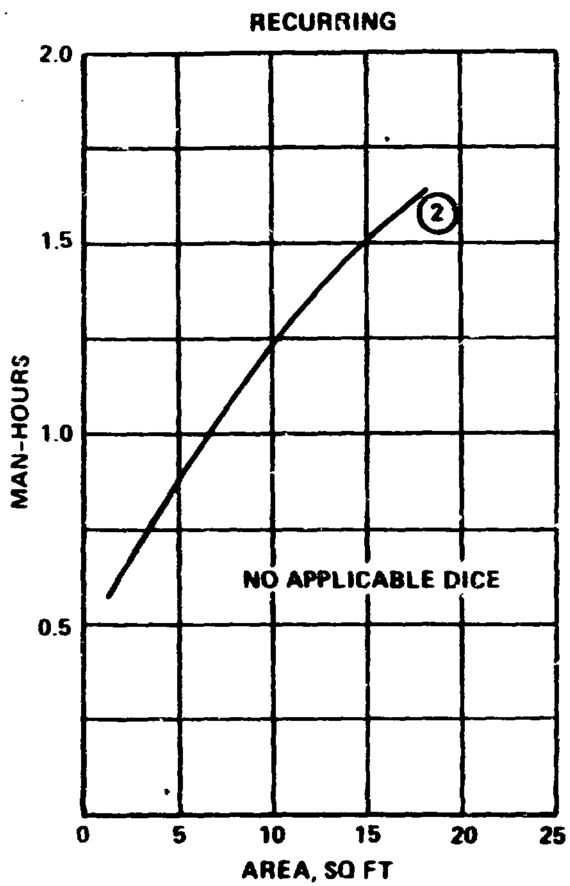
*NO REVERSE CURVES

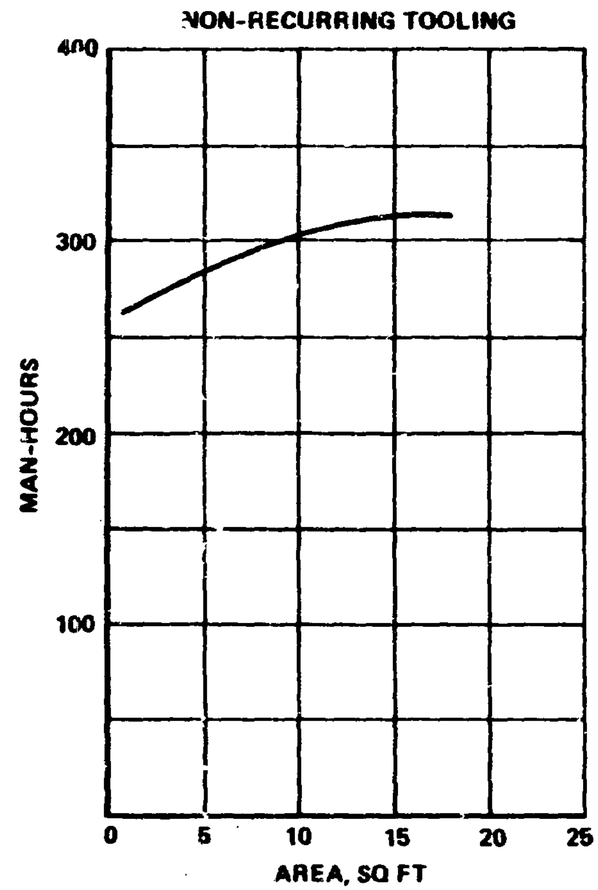
(2) FORMED IN "O" OR "W" CONDITION, FINAL TEMPER T81

CED—A-21

ALUMINUM FAIRING, LOWEST COST PROCESS DROP HAMMER (INCLUDES PROCESS AND TRIM)



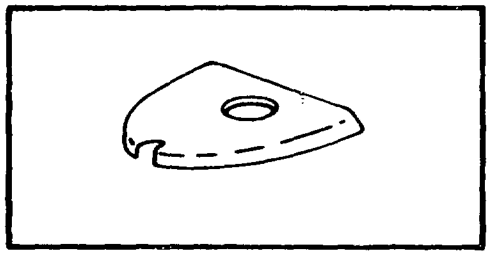


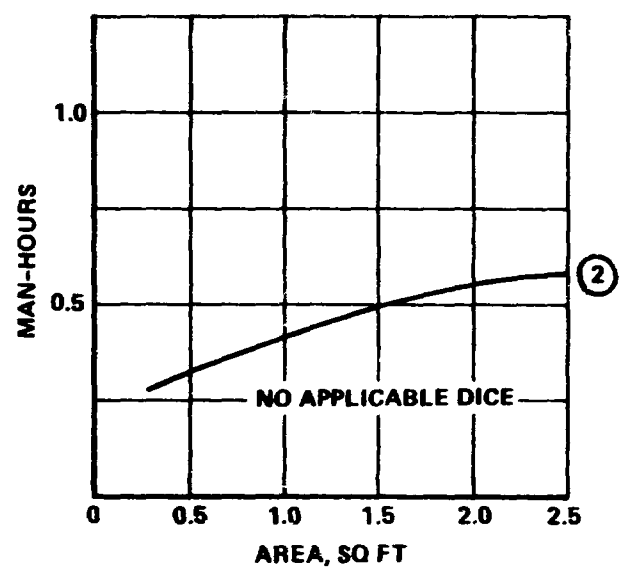


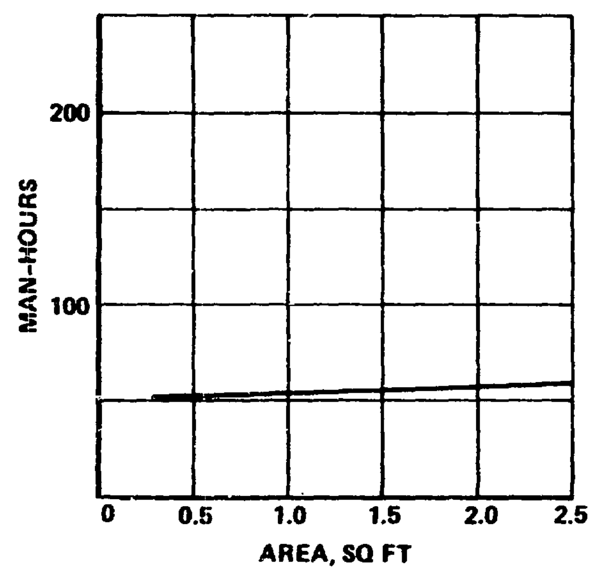
(2) FORMED IN "O" OR "W" CONDITION, FINAL TEMPER T62

CED—A-22

ALUMINUM RIB, LOWEST COST PROCESS
RUBBER PRESS

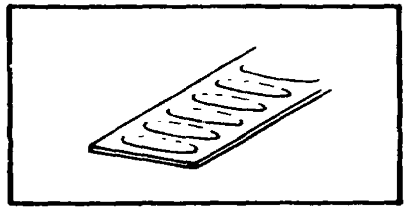






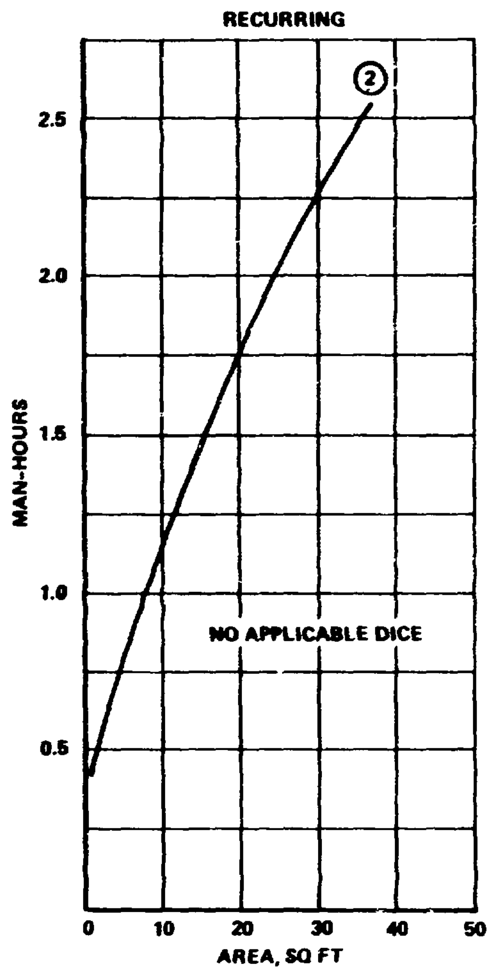
CED—A-23

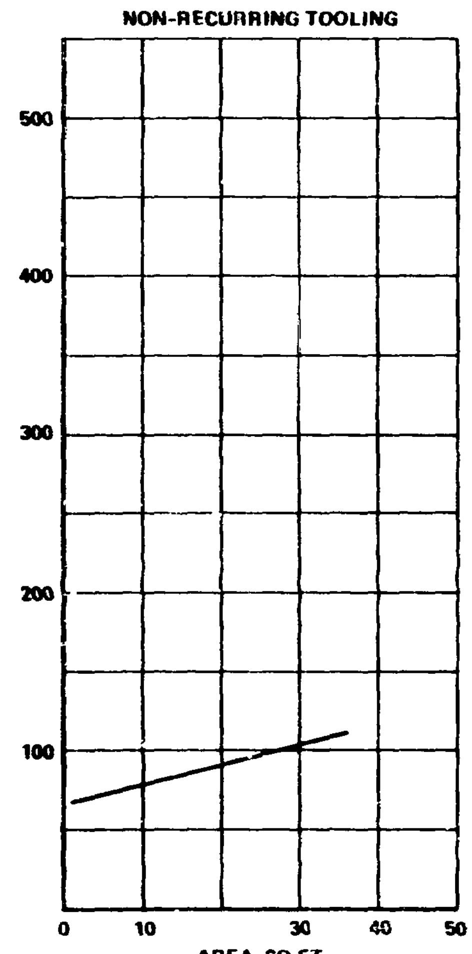
(2) FORMED IN "O" OR "W" CONDITION, FINAL TEMPER T62



ALUMINUM BEADED PANEL, LOWEST COST PROCESS

RUBBER PRESS





CED—A-24

(2) FORMED IN "O" OR "W" CONDITION, FINAL TEMPER T62

4.1.5.2 Formats for Steel Sheet Metal Aerospace Discrete Parts Lowest Cost Processes

The following conditions apply to utilizing the formats in this section:

(1) Review ground rules in section for considerations and limitations.

(2) Consider step occurring in recurring cost man-hours for lineal shapes, at length of 6 feet, due to requirement of two persons for certain manufacturing operations.

(3) Bend radius limitations for titanium:
- At room temperature forming $\geq$ 5t
- At elevated temperature forming $\geq$ 2t.

(4) Materials selection: The user of the MC/DG is cautioned with respect to the range of factors that can also play an important role, besides manufacturing cost, in the selection of an airframe material. The airframe design requirements may include:
- Elevated temperatures
- Operation in corrosive environments
- Higher acquisition costs might be acceptable due to lower operations and maintenance costs.

All factors must be carefully considered by the designer prior to selecting a material or design concept based on manufacturing cost.

(5) Review definitions in Section 2.2 "Terms and Abbreviations". However, important terminology used on most formats are:

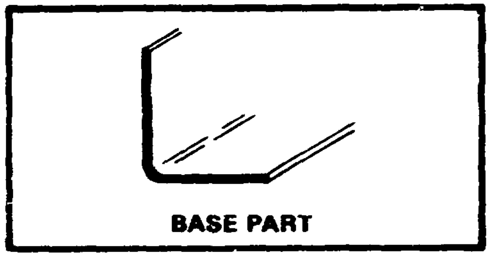
(a) Base Part: A detail part in its simplest form, i.e., without complexities such as heat treatment, cutouts, and joggles.

(b) Designer-Influenced Cost Elements (DICE): Includes joggles, cutouts, lightening holes, and special tolerances that add cost to the base part configuration. These additional costs are due to the increased fabrication operations and tooling required over the standard manufacturing method (SMM) for the base part.

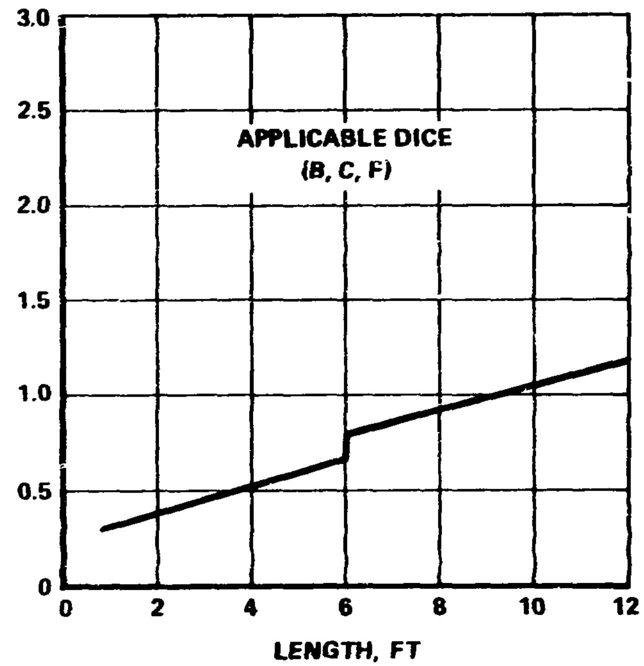
(c) Detail or Discrete Parts: A distinct airframe structural part which may incorporate complexities, e.g., a base part plus DICE, ready for assembly to perform its required function in the airframe.

STEEL ANGLE, STRAIGHT MEMBER, LOWEST COST PROCESS

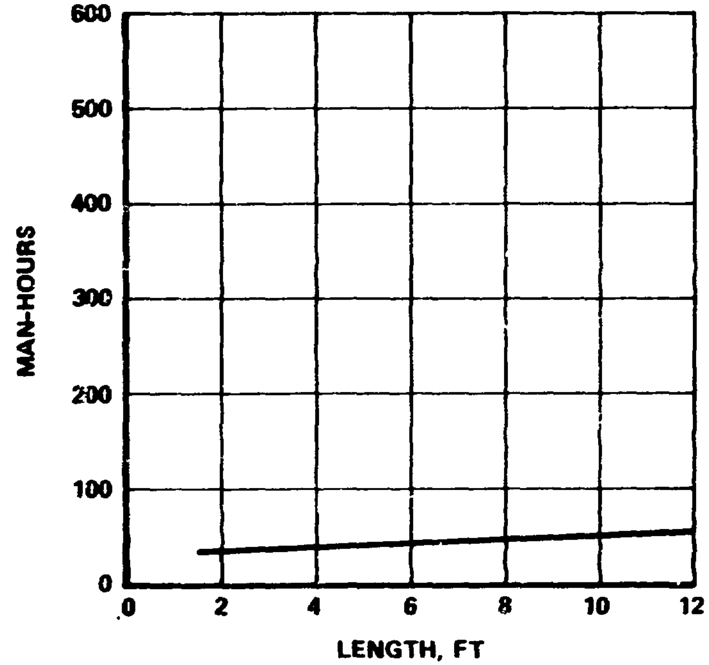
BRAKE FORM



RECURRING



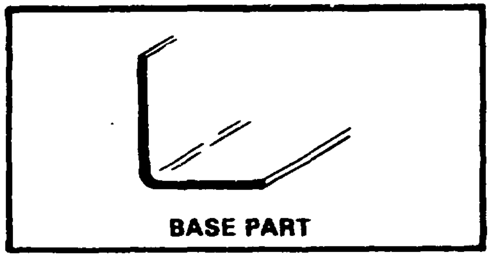
NON-RECURRING TOOLING

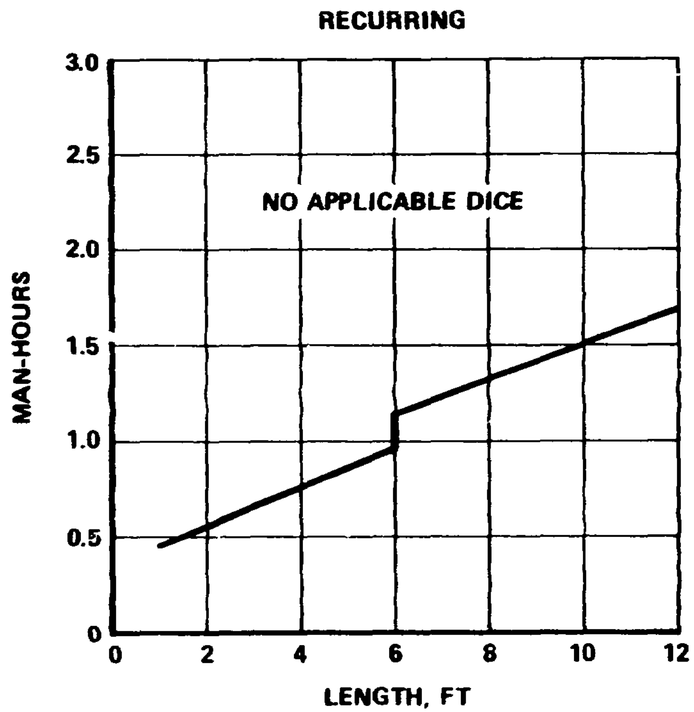


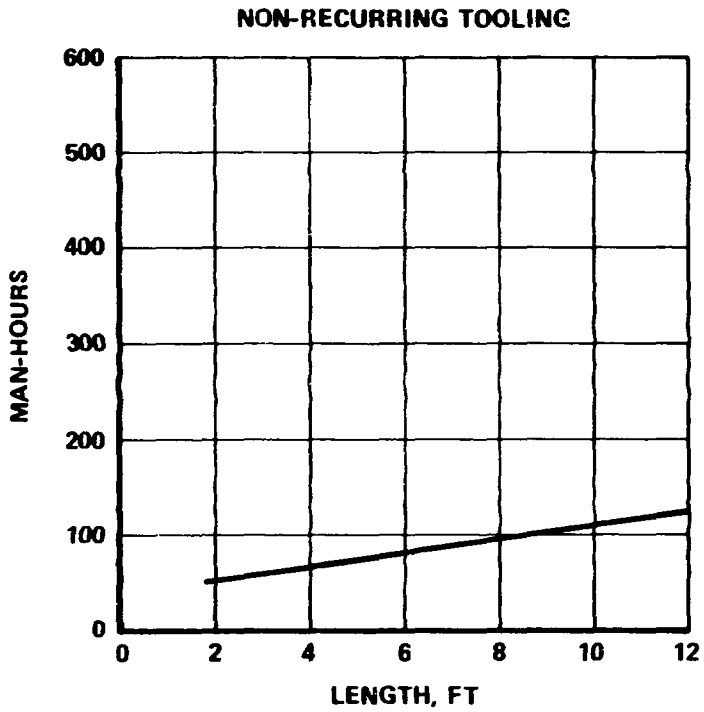
CED—S-1

STEEL ANGLE, CONTOURED MEMBER*, LOWEST COST PROCESS

RUBBER PRESS





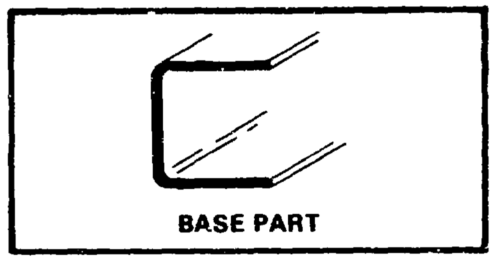


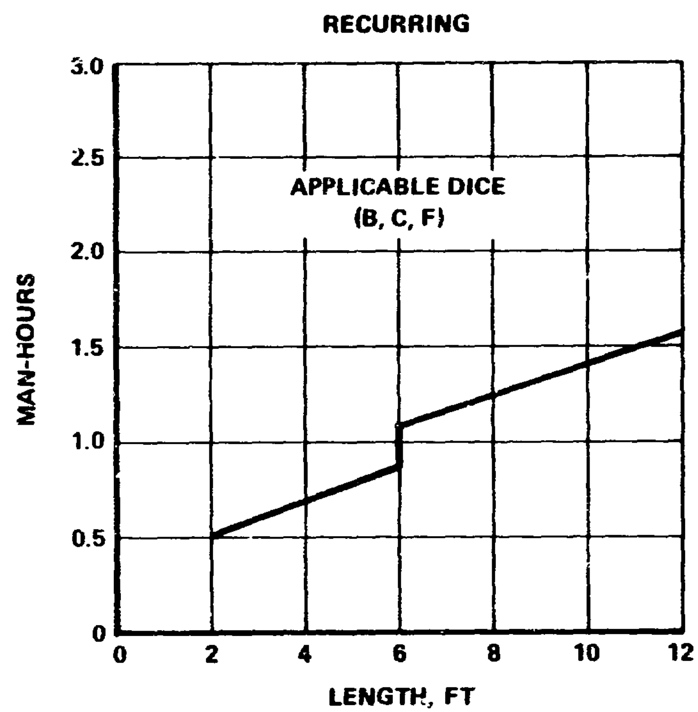
*NO REVERSE CURVES

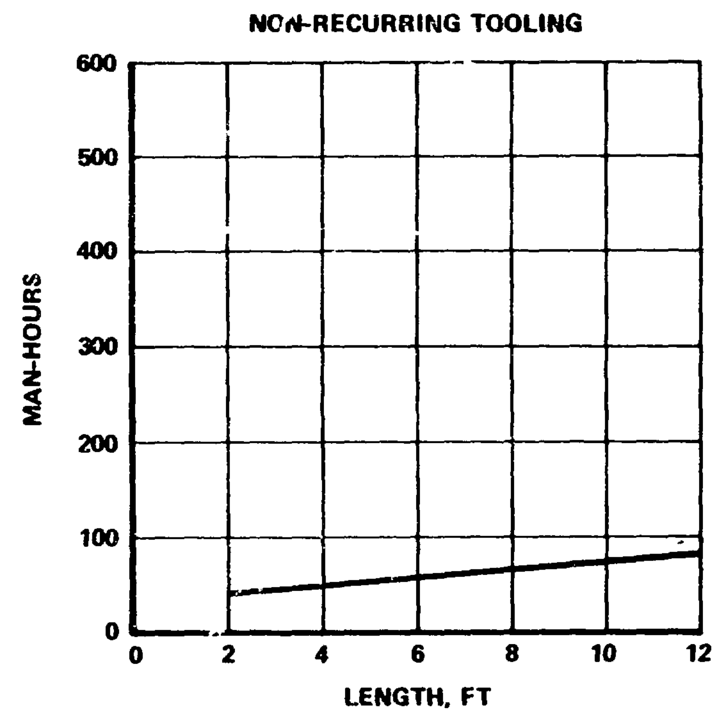
CED—S-2

STEEL CHANNEL, STRAIGHT MEMBER, LOWEST COST PROCESS

BRAKE FORM



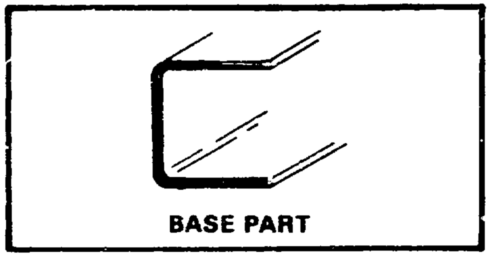


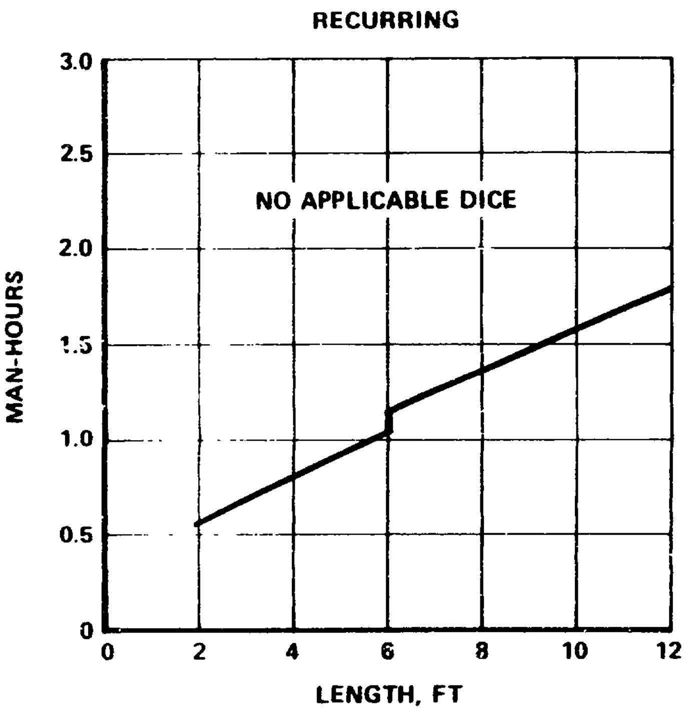


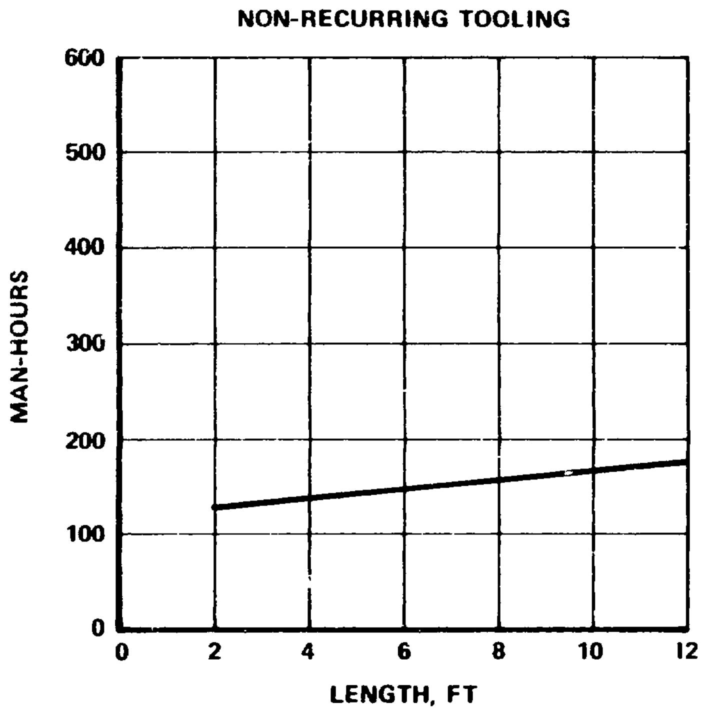
CED—S-3

STEEL CHANNEL, CONTOURED MEMBER*, LOWEST COST PROCESS

RUBBER PRESS





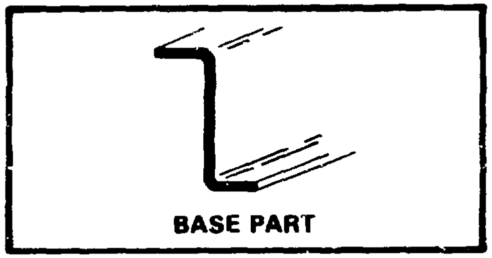


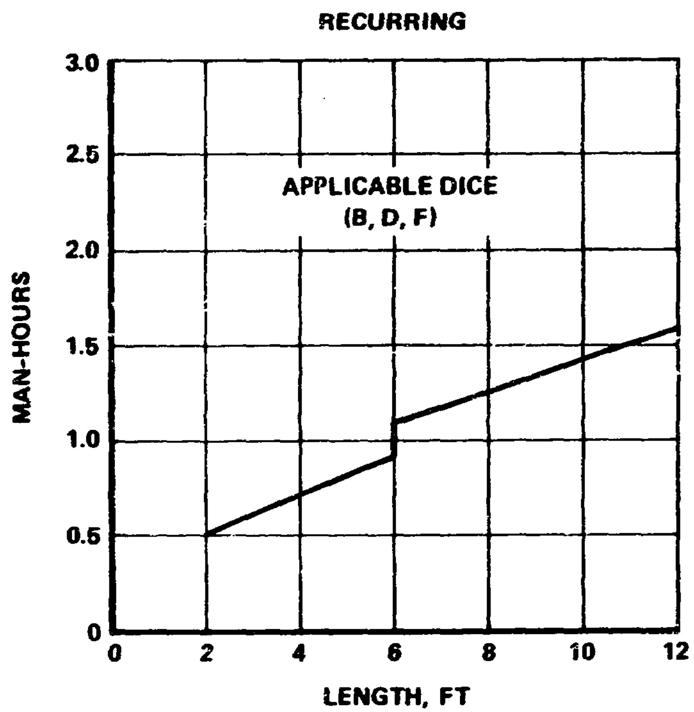
*NO REVERSE CURVES

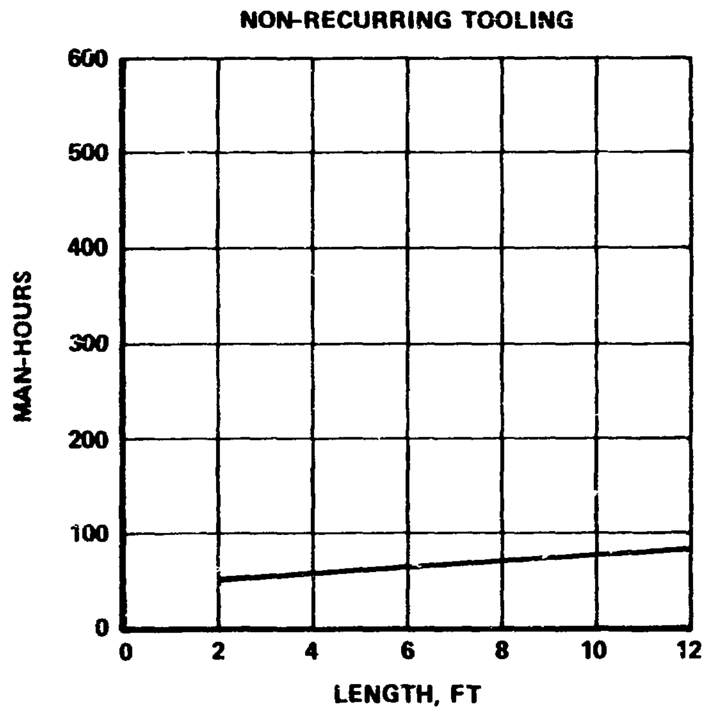
CED—S-4

STEEL ZEE, STRAIGHT MEMBER, LOWEST COST PROCESS

BRAKE FORM





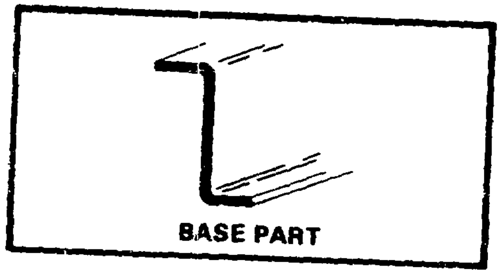


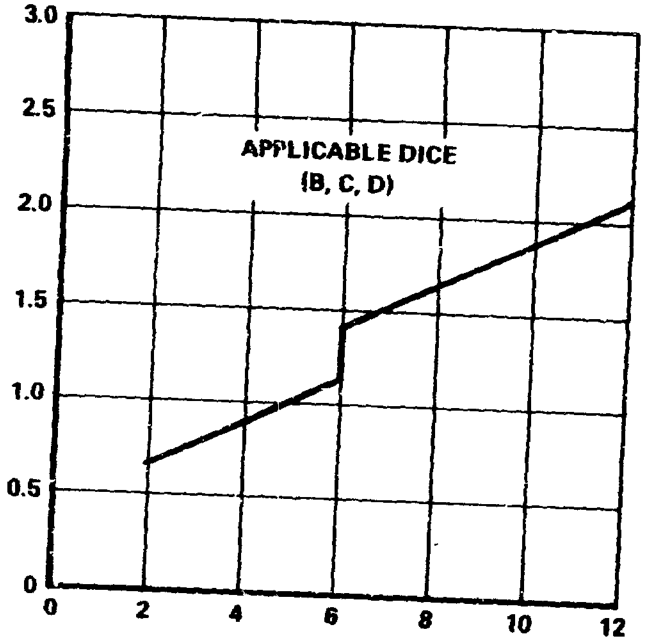
CED—S-5

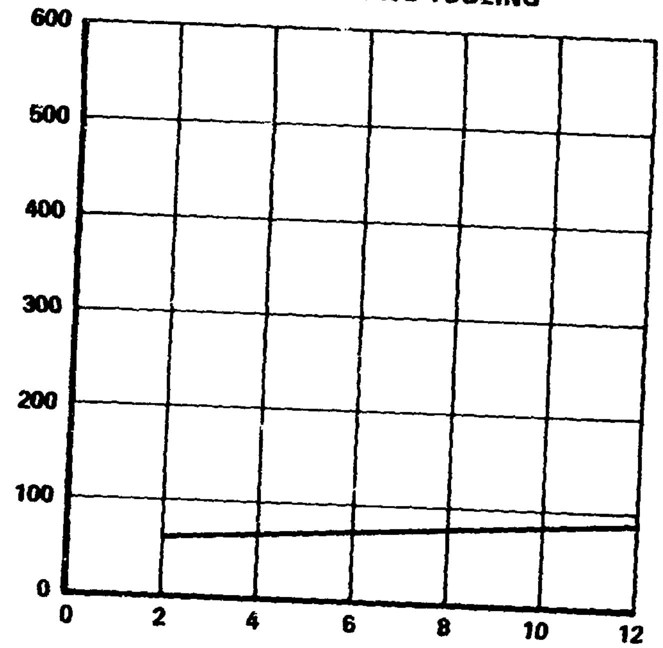
FTR450261000U
3 Jan 1983

STEEL ZEE, CYLINDRICALLY CONTOURED MEMBER, LOWEST COST PROCESS

BRAKE/ROLL



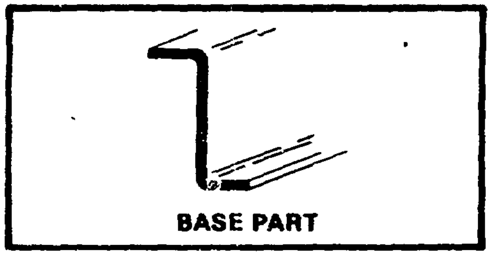


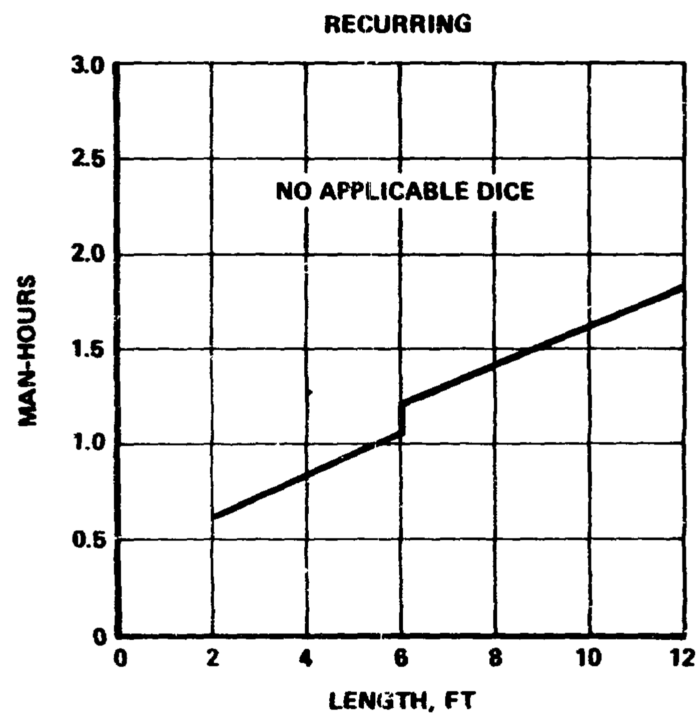


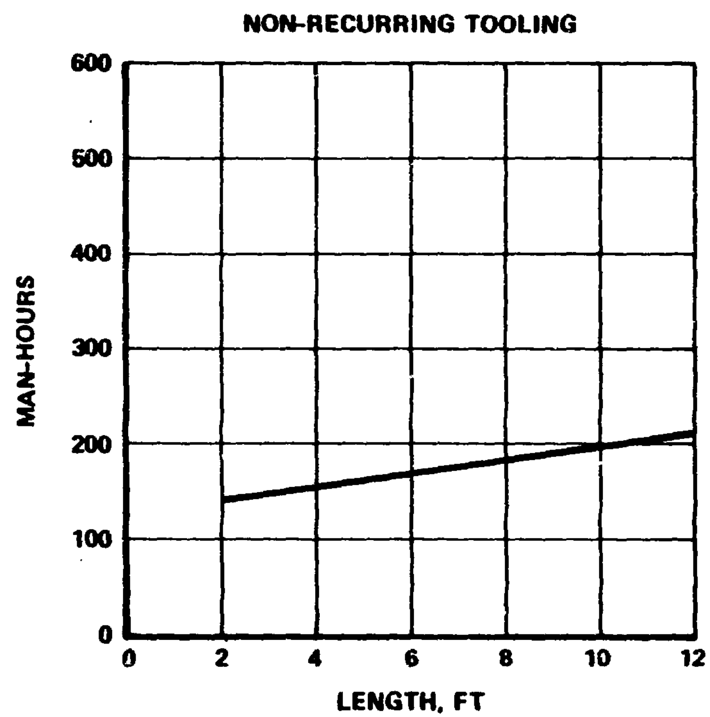
CED—S-6

STEEL NON-CYLINDRICAL CURVATURE SKIN*, LOWEST COST PROCESS

STRETCH FORM





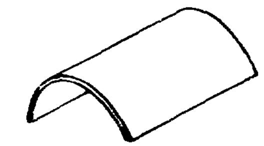


*NO REVERSE CURVES

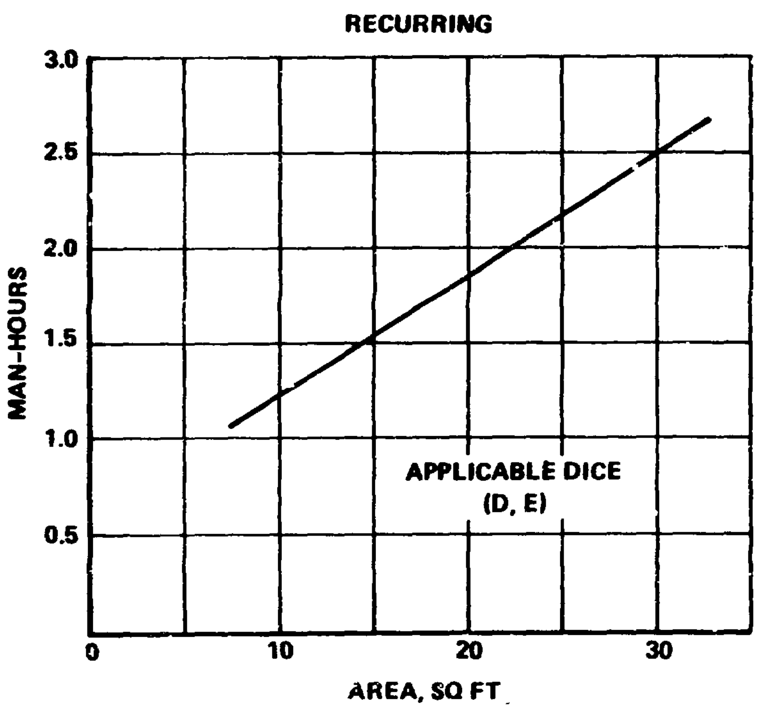
CED—S-7

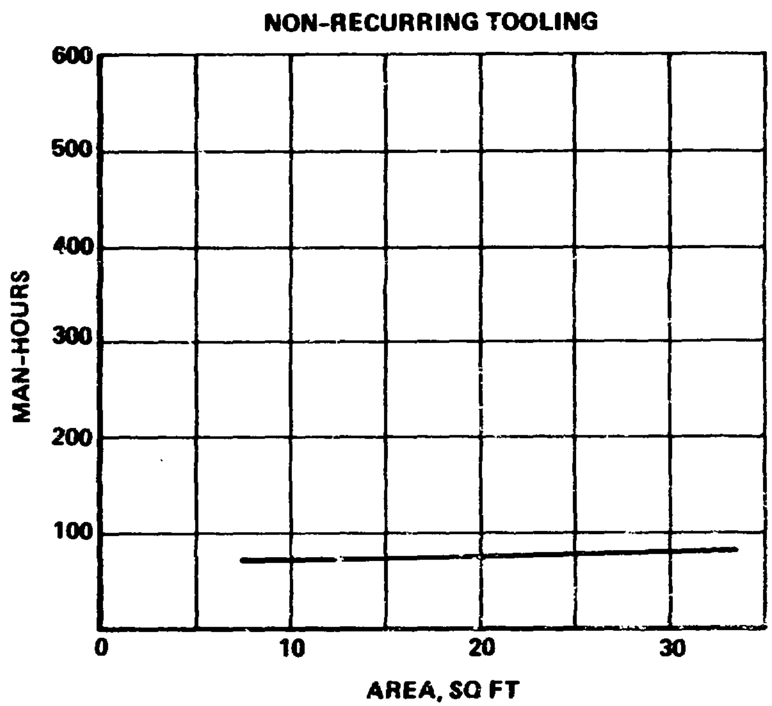
STEEL CYLINDRICAL CURVATURE SKIN, LOWEST COST PROCESS

FARNHAM ROLL



BASE PART

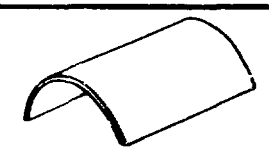




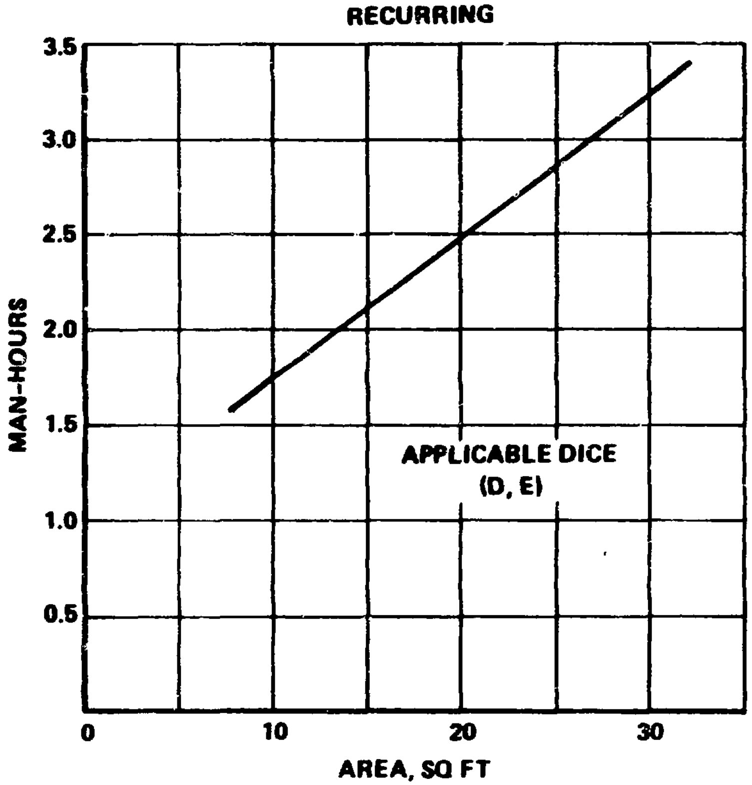
CED—S-8

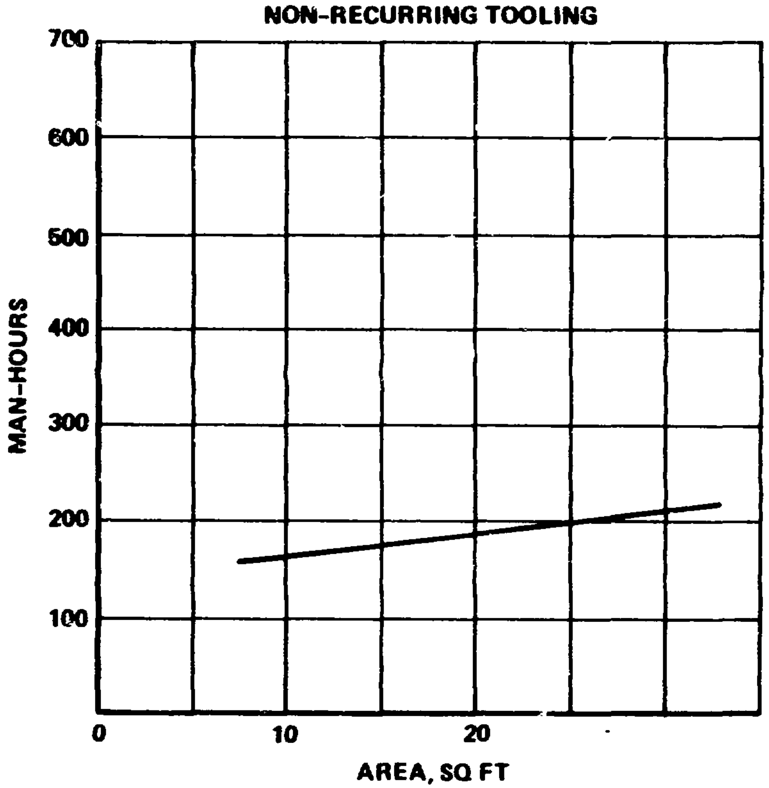
STEEL NON-CYLINDRICAL CURVATURE SKIN*, LOWEST COST PROCESS

STRETCH FORM



BASE PART

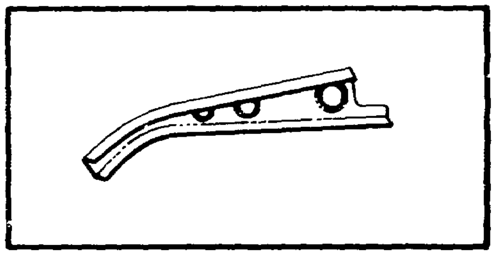


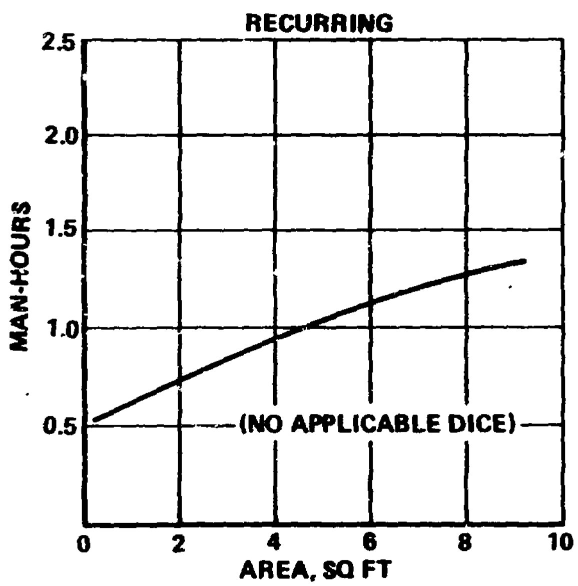


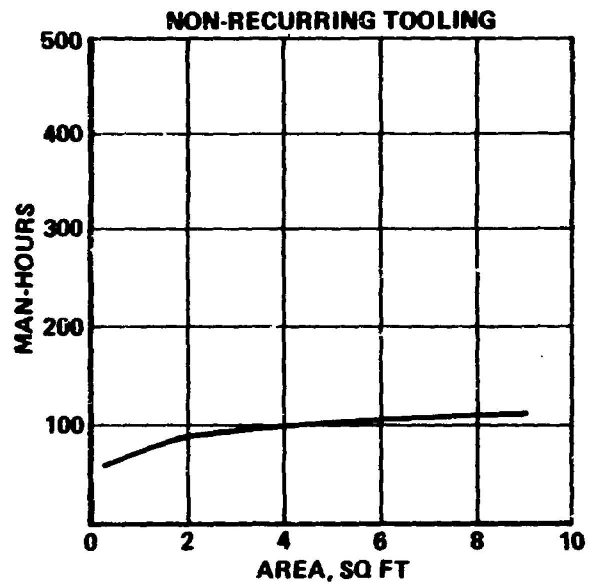
* NO REVERSE CURVES

CED—S-9

STEEL ... ME, LOWEST COST PROCESS
RUBBER PRESS







CED—S-10

4.1.5.3 <u>Formats for Titanium Sheet Metal Aerospace Discrete Parts Lowest Cost Processes</u>

The following conditions apply to utilizing the formats in this section:

(1) Review ground rules in section for considerations and limitations.

(2) Consider step occurring in recurring cost man-hours for lineal shapes, at length of 6 feet, due to requirement of two persons for certain manufacturing operations.

(3) Bend radius limitations for titanium:
- At room temperature forming $\geq$ 5t
- At elevated temperature forming $\geq$ 2t.

(4) Materials selection: The user of the MC/DG is cautioned with respect to the range of factors that can also play an important role, besides manufacturing cost, in the selection of an airframe material. The airframe design requirements may include:
- Elevated temperatures
- Operation in corrosive environments
- Higher acquisition costs might be acceptable due to lower operations and maintenance costs.

All factors must be carefully considered by the designer prior to selecting a material or design concept based on manufacturing cost.

(5) Review definitions in Section 2.2 "Terms and Abbreviations". However, important terminology used on most formats are:

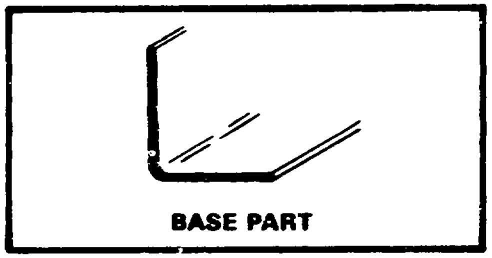
(a) <u>Base Part</u>: A detail part in its simplest form, i.e., without complexities such as heat treatment, cutouts, and joggles.

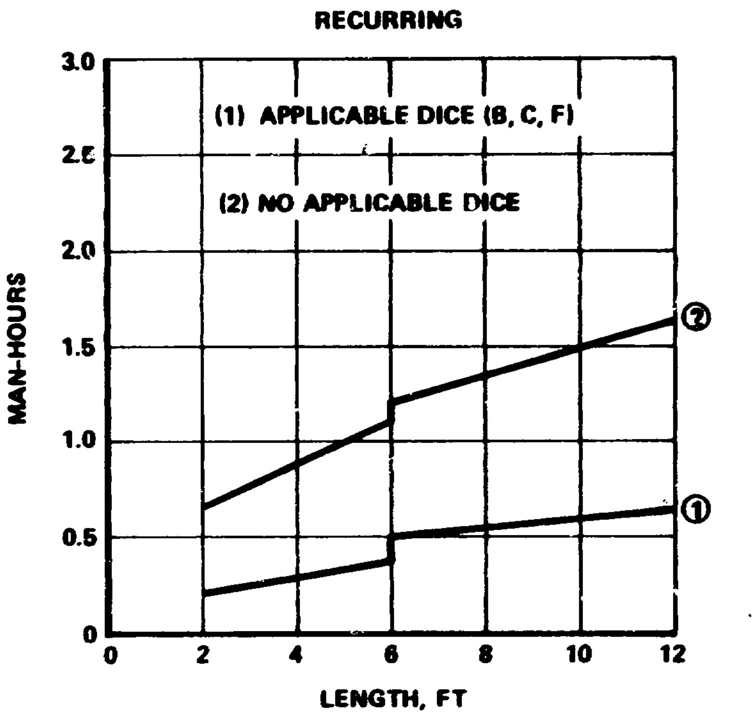
(b) <u>Designer-Influenced Cost Elements (DICE)</u>: Includes joggles, cutouts, lightening holes, and special tolerances that add cost to the base part configuration. These additional costs are due to the increased fabrication operations and tooling required over the standard manufacturing method (SMM) for the base part.

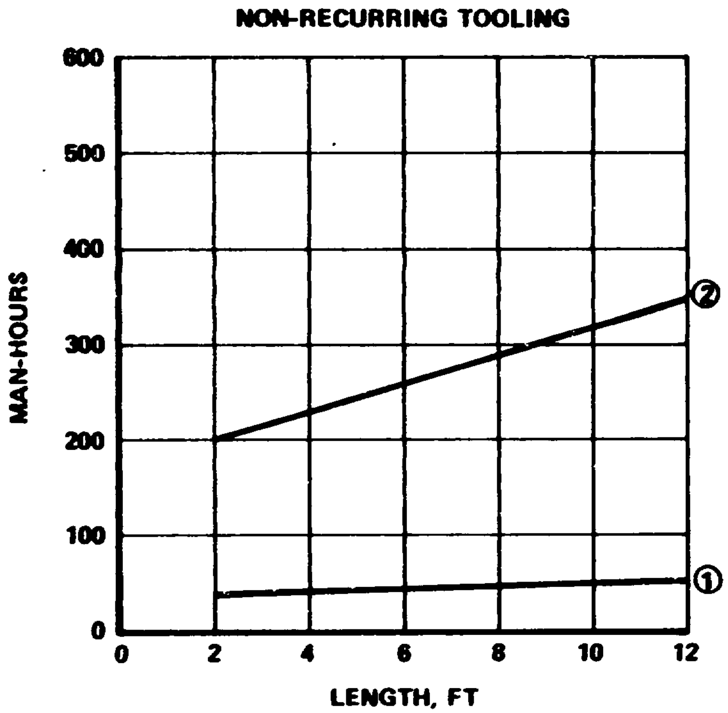
(c) <u>Detail or Discrete Parts</u>: A distinct airframe structural part which may incorporate complexities, e.g., a base part plus DICE, ready for assembly to perform its required function in the airframe.

TITANIUM ANGLE, STRAIGHT MEMBER, LOWEST COST PROCESS

BRAKE FORM OR PREFORM/HOT SIZE







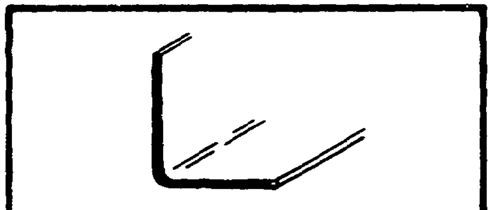
(1) ROOM TEMPERATURE BRAKE FORM, MINIMUM BEND RADIUS = 5t

(2) PREFORM/HOT SIZE, MINIMUM BEND RADIUS = 2t

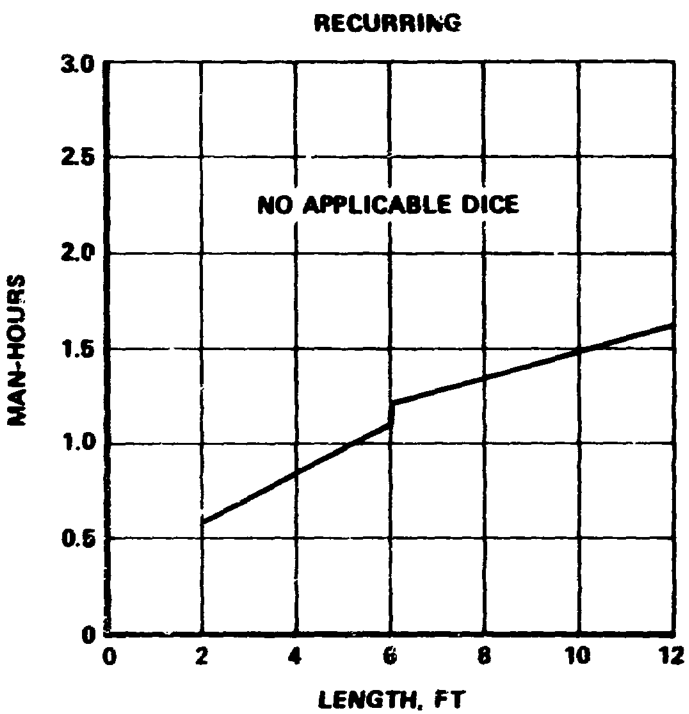
CED—T-1

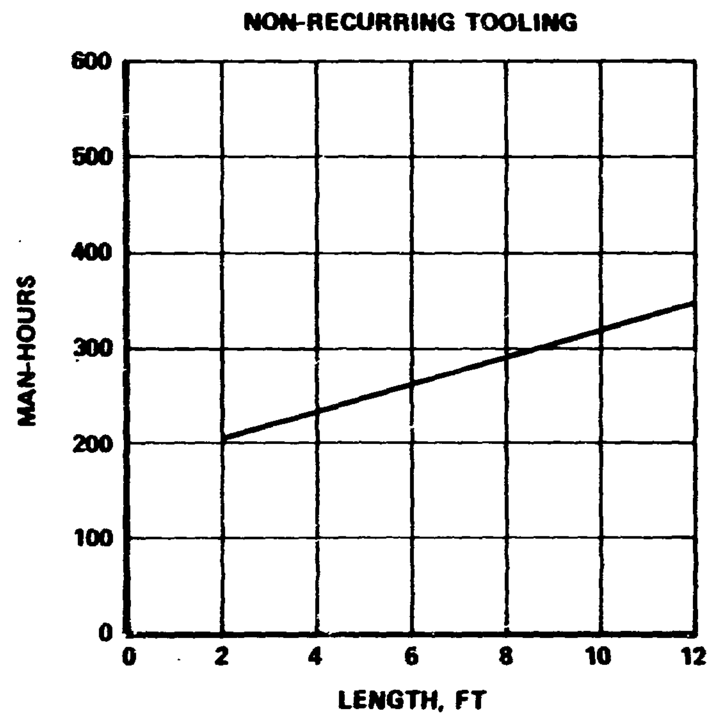
TITANIUM ANGLE, CONTOURED MEMBER, LOWEST COST PROCESS

PREFORM/HOT SIZE



BASE PART

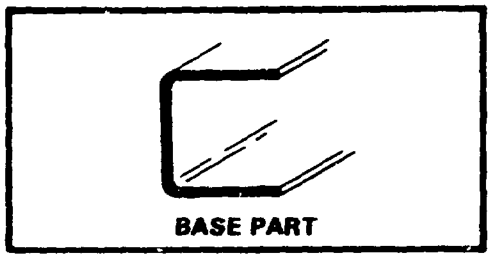


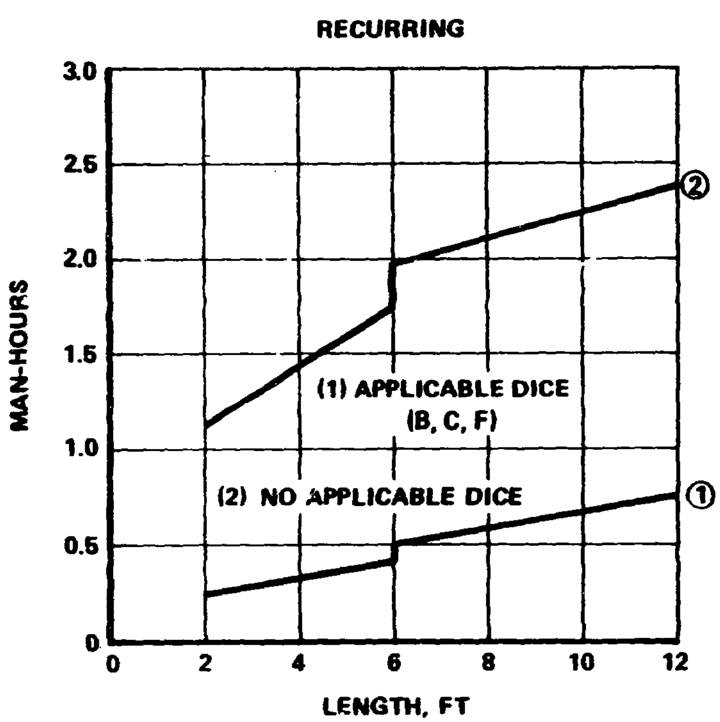


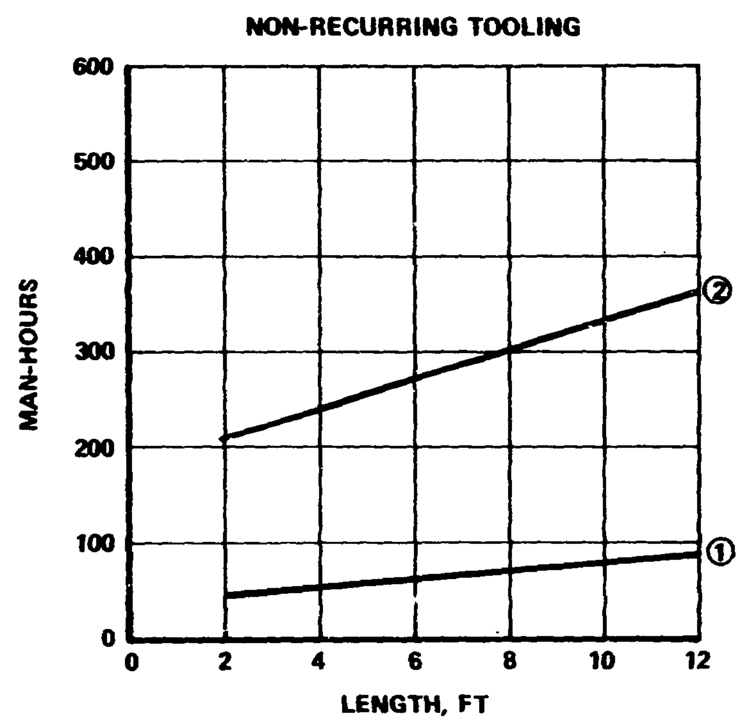
MINIMUM BEND RADIUS = 2t

CED—T-2

TITANIUM CHANNEL, STRAIGHT MEMBER, LOWEST COST PROCESS
BRAKE FORM AND PREFORM/HOT SIZE





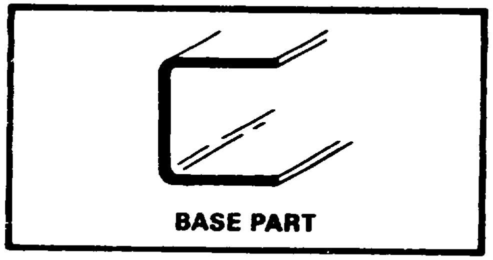


(1) ROOM TEMPERATURE BRAKE FORM, *MINIMUM BEND RADIUS* = 5t
(2) PREFORM/HOT SIZE, *MINIMUM BEND RADIUS* = 2t

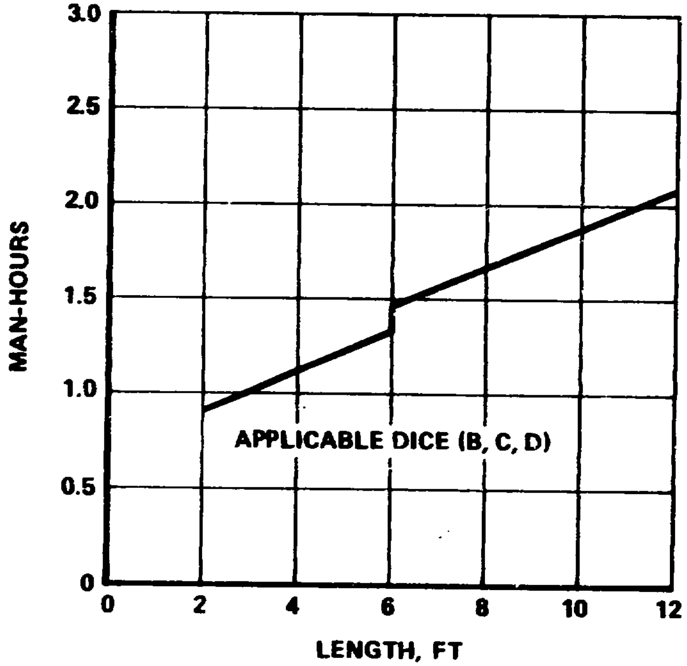
CED—T-3

TITANIUM CHANNEL, CONTOURED MEMBER,* LOWEST COST PROCESS

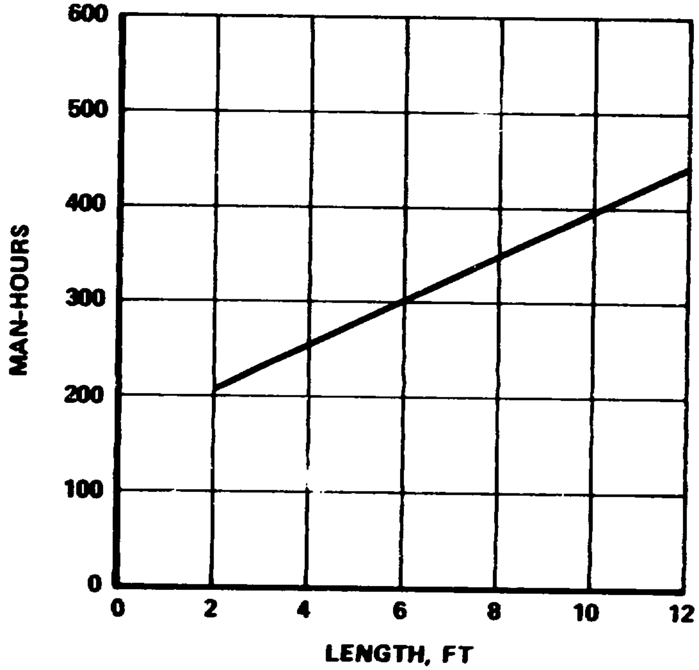
BRAKE/HOT STRETCH



RECURRING



NON-RECURRING TOOLING

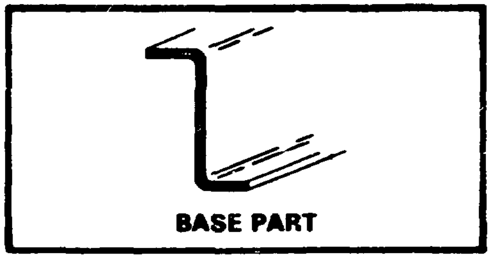


*NO REVERSE CURVATURE

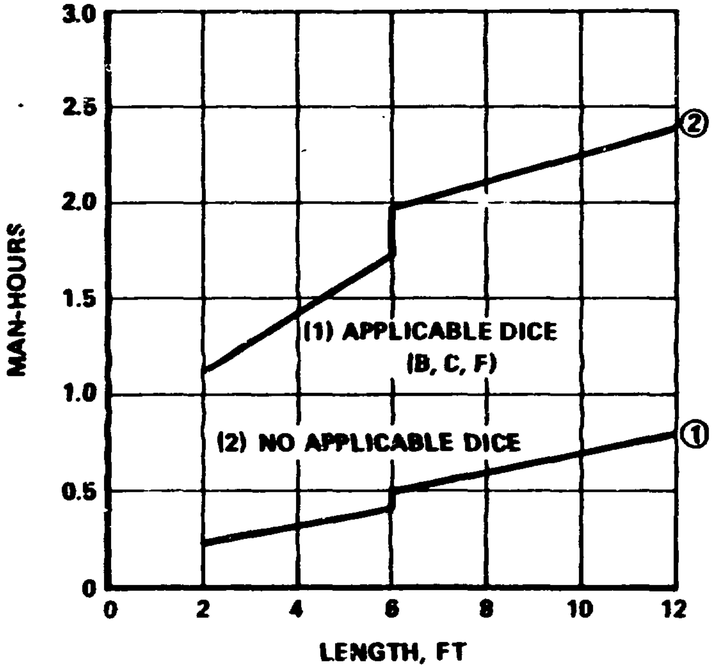
CED—T-4

TITANIUM ZEE, STRAIGHT MEMBER, LOWEST COST PROCESS

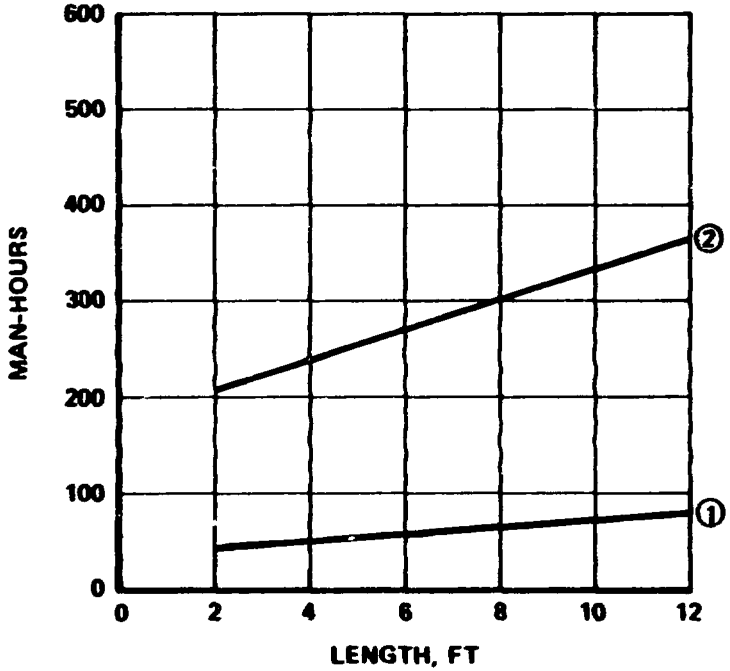
BRAKE FORM OR PREFORM/HOT SIZE



RECURRING



NON-RECURRING TOOLING

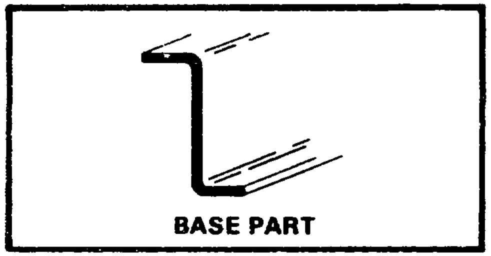


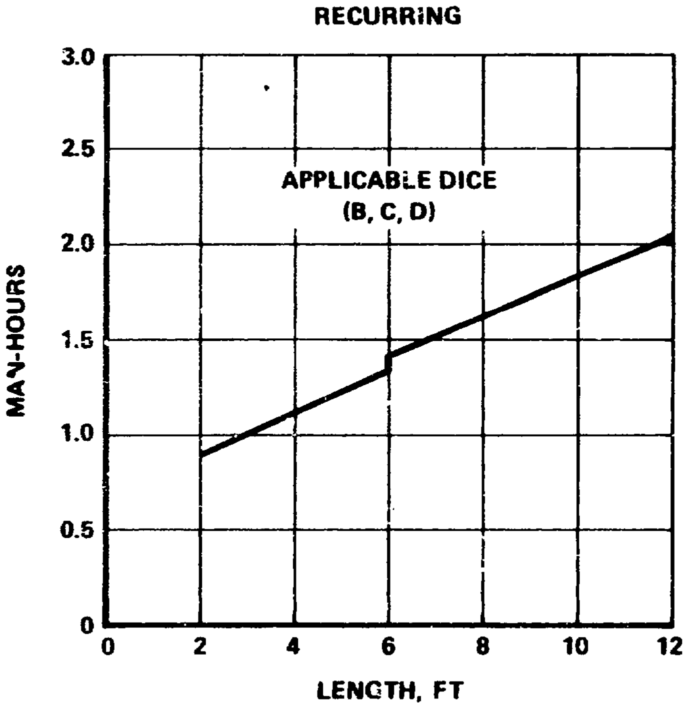
(1) ROOM TEMPERATURE BRAKE FORM, MINIMUM BEND RADIUS = 5t
(2) PREFORM/HOT SIZE, MINIMUM BEND RADIUS = 2t

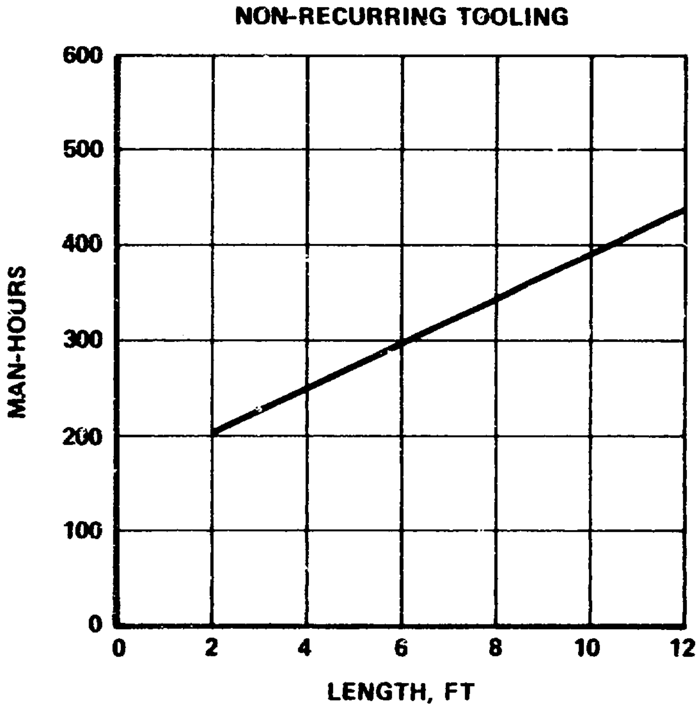
CED—T-5

TITANIUM ZEE, CONTOURED MEMBER,* LOWEST COST PROCESS

BRAKE/HOT STRETCH





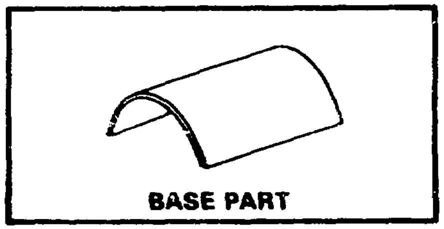


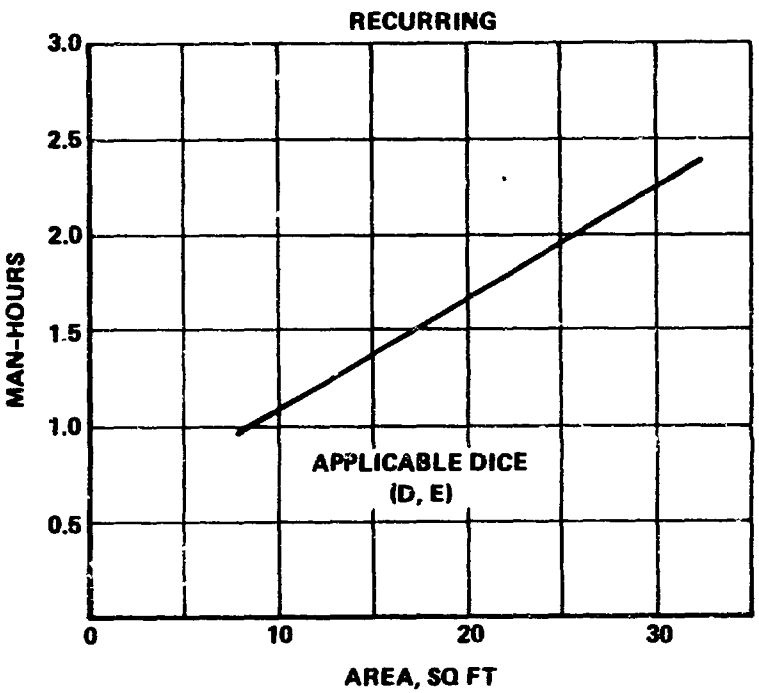
MINIMUM BEND RADIUS = 2t
*NO REVERSE CURVATURE

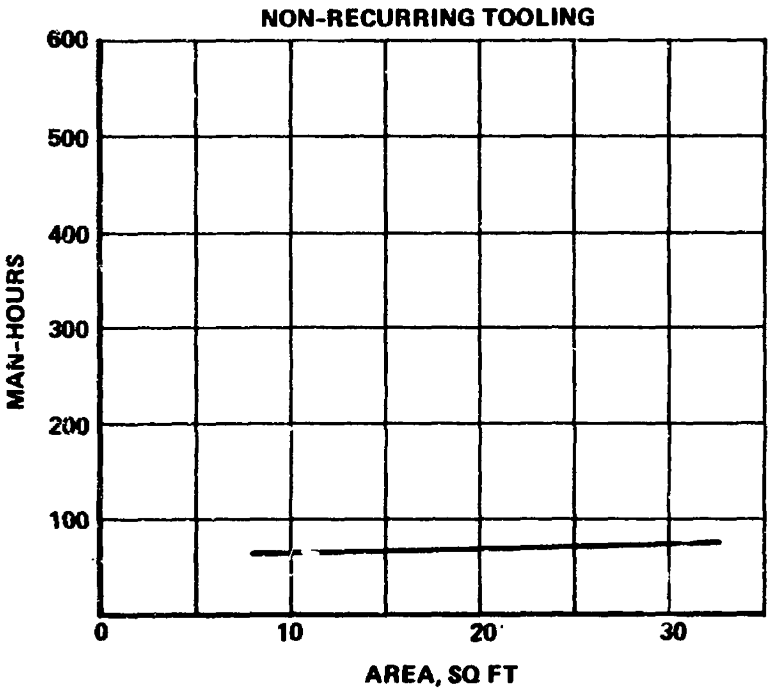
CED—T-6

TITANIUM CYLINDRICAL CURVATURE SKIN, LOWEST COST PROCESS

FARNHAM ROLL



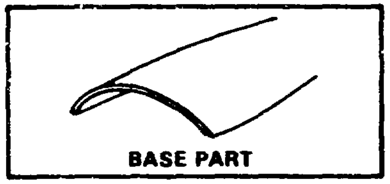




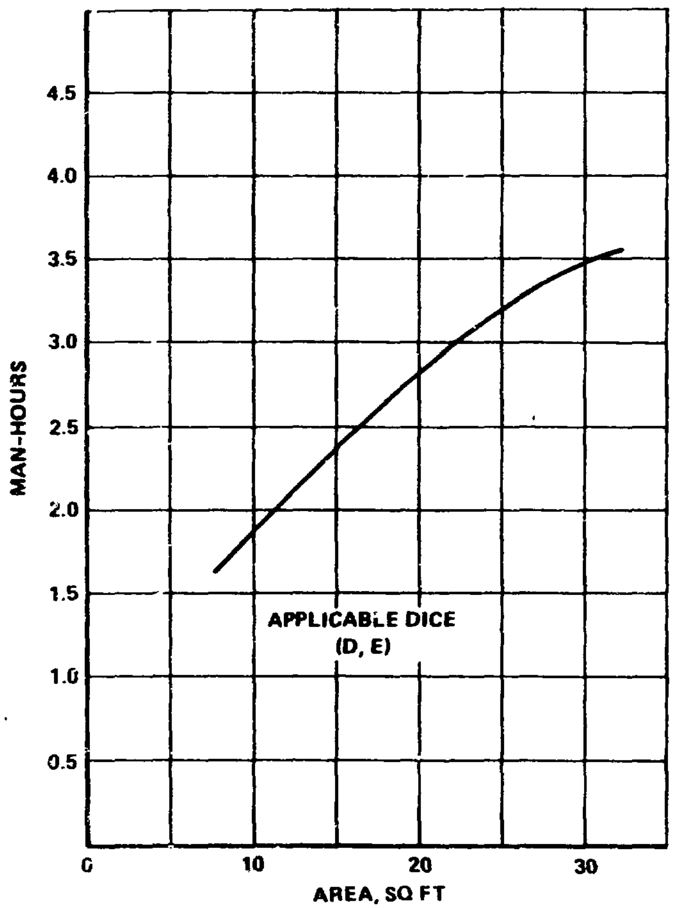
CED—T-7

TITANIUM NON-CYLINDRICAL CURVATURE SKIN*, LOWEST COST PROCESS

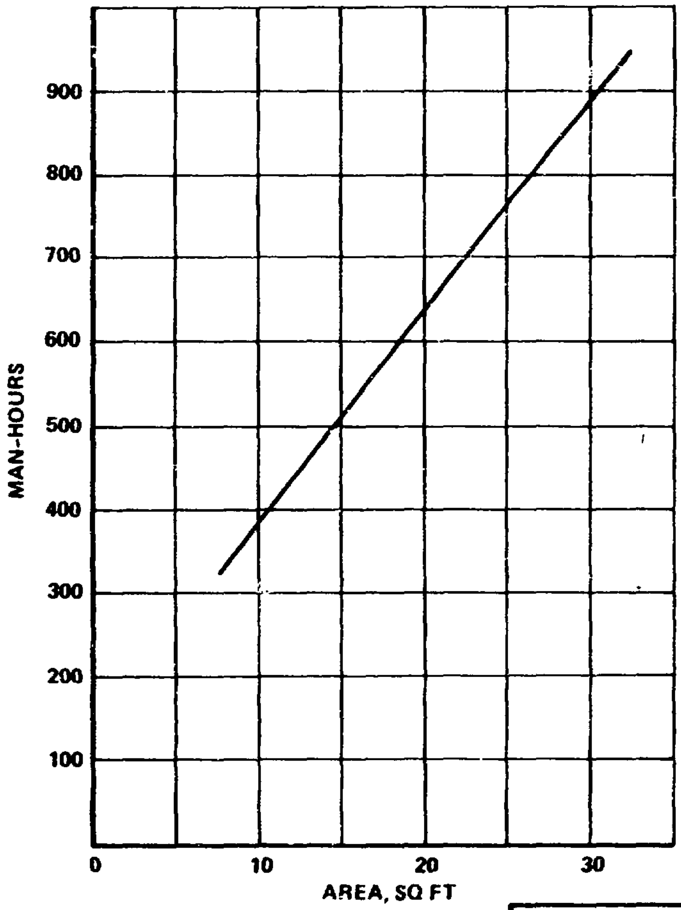
CREEP FORM



RECURRING



NON-RECURRING TOOLING

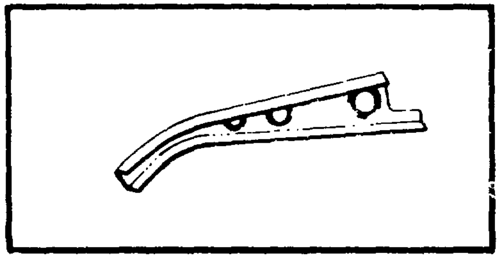


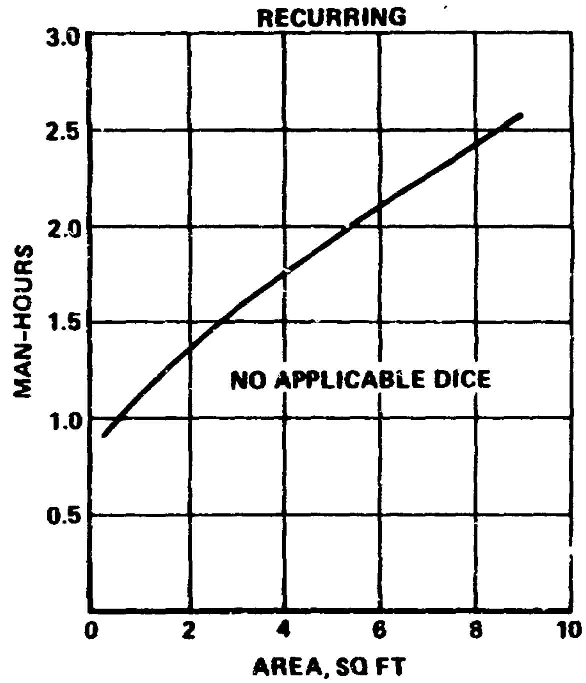
*NO REVERSE CURVES

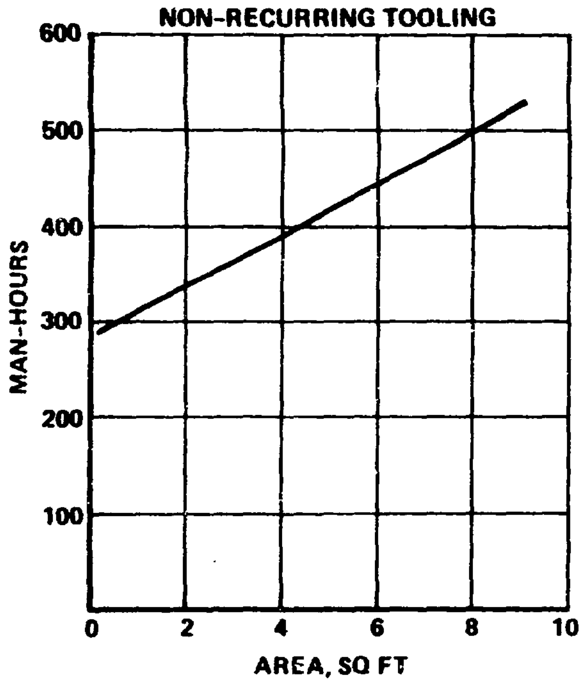
CED—T-8

TITANIUM FRAME, LOWEST COST PROCESS

HOT PRESS







CED—T-9

4.1.5.4 Formats for Designer-Influenced Cost Elements (DICE) for Sheet Metal Aerospace Discrete Parts

The following conditions apply to utilizing the formats in this section:

(1) Review ground rules in section for considerations and limitations.

(2) Consider step occurring in recurring cost man-hours for lineal shapes, at length of 6 feet, due to requirement of two persons for certain manufacturing operations.

(3) Bend radius limitations for titanium:
- At room temperature forming $\geq$ 5t
- At elevated temperature forming $\geq$ 2t.

(4) Materials selection: The user of the MC/DG is cautioned with respect to the range of factors that can also play an important role, besides manufacturing cost, in the selection of an airframe material. The airframe design requirements may include:
- Elevated temperatures
- Operation in corrosive environments
- Higher acquisition costs might be acceptable due to lower operations and maintenance costs.

All factors must be carefully considered by the designer prior to selecting a material or design concept based on manufacturing cost.

(5) Review definitions in Section 2.2 "Terms and Abbreviations". However, important terminology used on most formats are:

(a) Base Part: A detail part in its simplest form, i.e., without complexities such as heat treatment, cutouts, and joggles.

(b) Designer-Influenced Cost Elements (DICE): Includes joggles, cutouts, lightening holes, and special tolerances that add cost to the base part configuration. These additional costs are due to the increased fabrication operations and tooling required over the standard manufacturing method (SMM) for the base part.

(c) Detail or Discrete Parts: A distinct airframe structural part which may incorporate complexities, e.g., a base part plus DICE, ready for assembly to perform its required function in the airframe.

GUIDE TO DESIGNER INFLUENCED COST ELEMENTS (DICE)

MATERIAL	DESIGNER INFLUENCED COST ELEMENTS / BASE PART MANUFACTURING METHOD	STANDARD JOGGLE	FLANGED HOLES	BEADS	HEAT TREATMENT	SPECIAL FINISH	SPECIAL TOLERANCE	LINEAL TRIM	END TRIM	CUTOUTS W/O FLANGES
ALUMINUM	BRAKE FORM	L	L	X	H	L	H	L	L	L
	BRAKE/BUFFALO ROLL	L	L	X	H	L	H	A	L	A
	BRAKE STRETCH	L	L	X	H	L	N	A	A	A
	DIE FORM	N	N	N	N	L	N	L	L	L
	DROP HAMMER	N	N	N	L	L	H	L	X	A
	FARNHAM ROLL	X	L	X	L	L	H	L	X	A
	ROUTED FLAT SHEET	X	L	X	L	L	H	L	X	L
	RUBBER PRESS	N	N	H	N	L	A	L	L	L
	STRETCH FORM	X	L	A	N	L	N	A	X	A
	YODER ROLL	L	L	X	H	L	H	A	A	A
	YODER STRETCH	L	L	H	N	L	N	A	L	A
TITANIUM	BRAKE FORM R.T.	A	L	X	X	L	H	H	H	L
	R.T. BRAKE/HOT STRETCH*	A	L	X	X	L	L	H	H	H
	CREEP FORM*	X	L	X	X	L	L	H	H	H
	FARNHAM ROLL	X	L	X	X	L	H	H	H	H
	HOT PRESS*	N	L	N	X	L	L	N	N	L
	PREFORM/HOT SIZE*	N	L	N	X	L	L	N	N	L
STEEL	BRAKE AND BUFFALO ROLL	A	L	X	N	L	H	H	A	L
	BRAKE FORM R.T.	A	L	X	N	L	H	L	L	L
	BRAKE/R.T. STRETCH	A	L	X	N	L	A	H	L	A
	FARNHAM ROLL	X	L	X	N	L	H	H	L	A
	RUBBER PRESS	N	N	N	N	L	A	L	L	L
	STRETCH FORM	X	L	X	N	L	A	H	A	L

*Denotes one or more elevated temperature processing steps.

LEGEND

RATING	
X	NOT APPLICABLE
N	NO ADDITIONAL COST INCL. IN BASE PART COST
L	LOW ADDITIONAL COST
A	AVERAGE ADDITIONAL COST
H	HIGH ADDITIONAL COST

Percentage Cost Ranges For Above

L	Up to 10%
A	10–30%
H	Above 30%

DICE-0

SHEET-METAL AEROSPACE DISCRETE PARTS

DICE MAN-HOURS

DICE	ALUMINUM 2024	STEEL PH15-7Mo	TITANIUM 6Al-4V
A HEAT TREATMENT[1]	T62: 0.8 X BASE PART COST T81: 0.1 X BASE PART COST	NOT APPLICABLE	NOT APPLICABLE
B STANDARD JOGGLE	0.008 + (0.006 X N*)	0.008 + (0.006 X N) COLD 0.011 + (0.018 X N) HOT	0.011 + (0.018 X N)
C STANDARD FLANGED HOLE	0.010 + (0.010 X N*)	0.010 + (0.010 X N)	0.010 + (0.010 X N)
D SPECIAL LINEAL TRIM	PER FOOT: 0.021 MAN-HOURS**	PER FOOT: 0.049 MAN-HOURS**	PER FOOT: 0.061 MAN-HOURS**
E STANDARD CUTOUT	0.024 MAN-HOURS PER FOOT OF PERIMETER	0.036 MAN-HOURS PER FOOT OF PERIMETER	0.036 MAN-HOURS PER FOOT OF PERIMETER

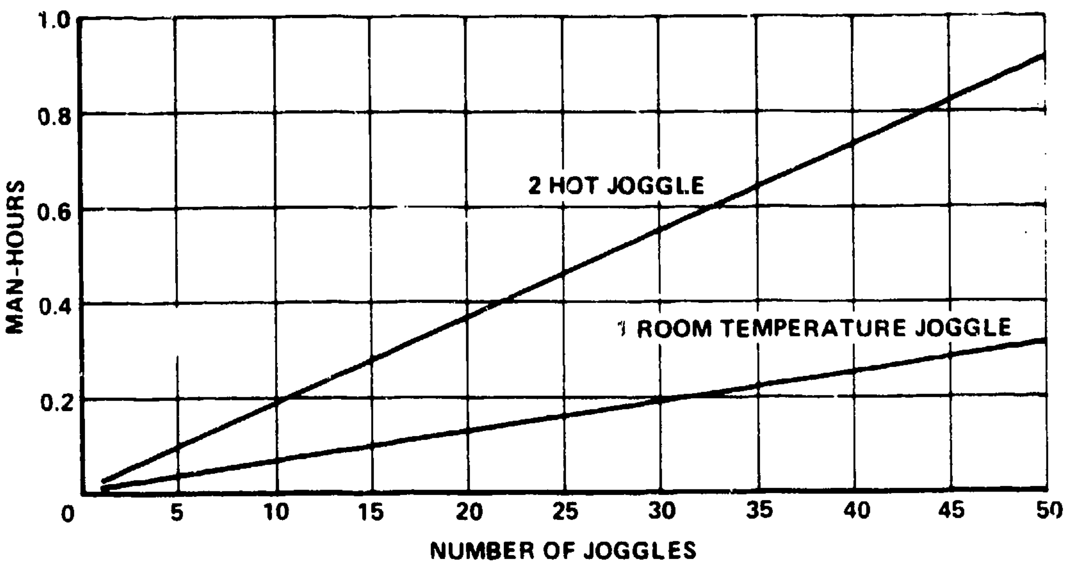
*N = NUMBER OF JOGGLES OR FLANGED HOLES.

**COST INCLUDES AMORTIZED TOOLING, AMORTIZED OVER 200 UNITS

1: THIS IS A COMPOSITE FACTOR FOR ALL SHAPES AND SIZES. FOR MORE DETAILS SEE DICE 6 OR DICE 7.

DICE-1

SHEET-METAL LINEAL PARTS— JOGGLE RECURRING COST

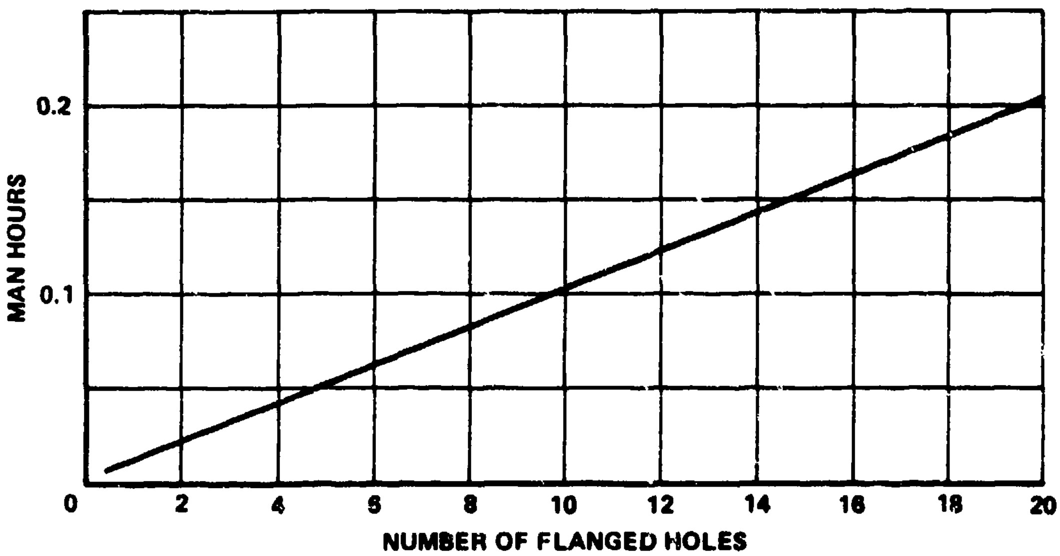


1 USED FOR ALUMINUM AND STEEL PARTS
2 US[illegible]OR T[illegible]UM PARTS

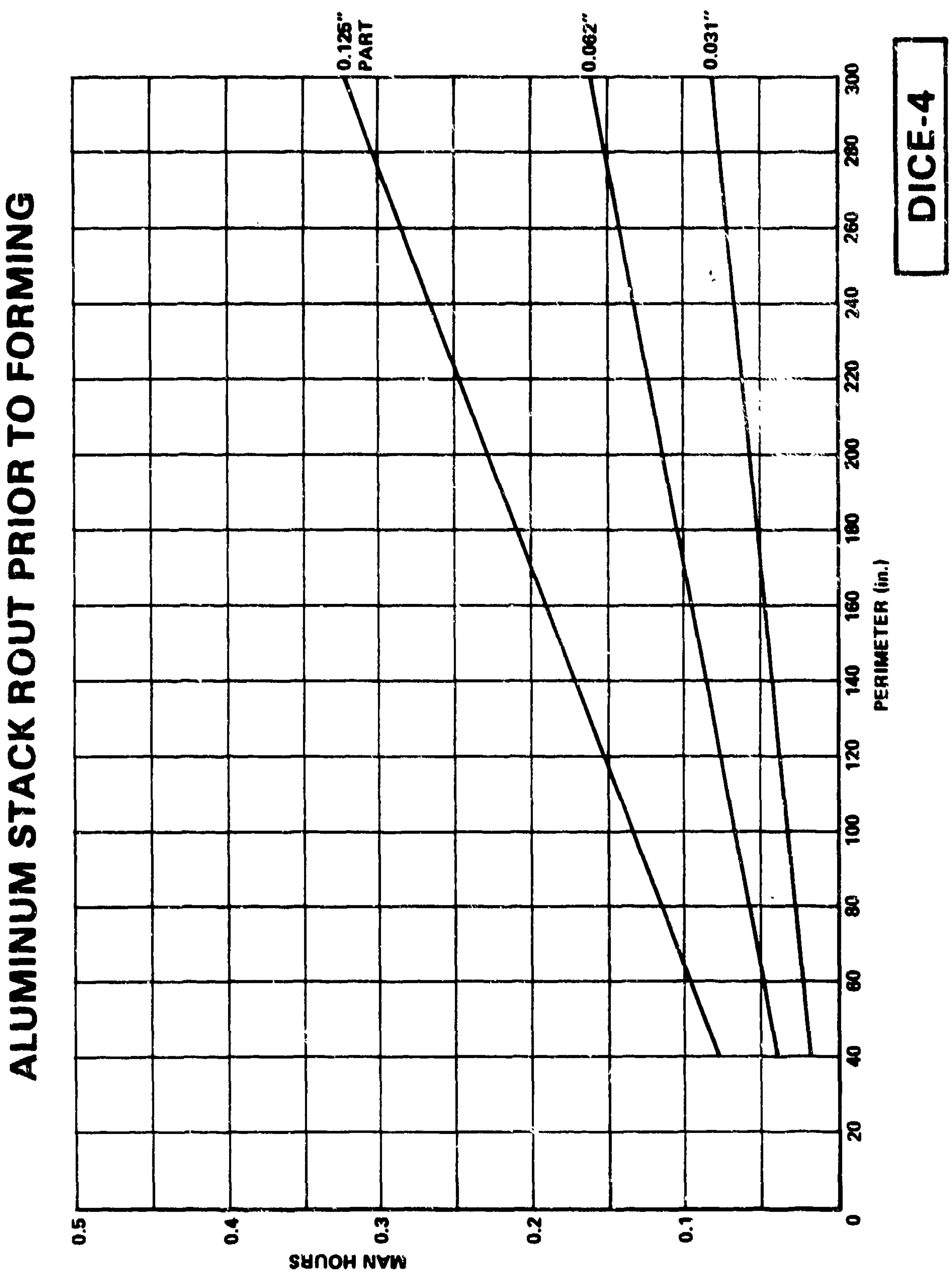
DICE-2

SHEET-METAL AEROSPACE DISCRETE PARTS— FLANGED HOLE RECURRING COST

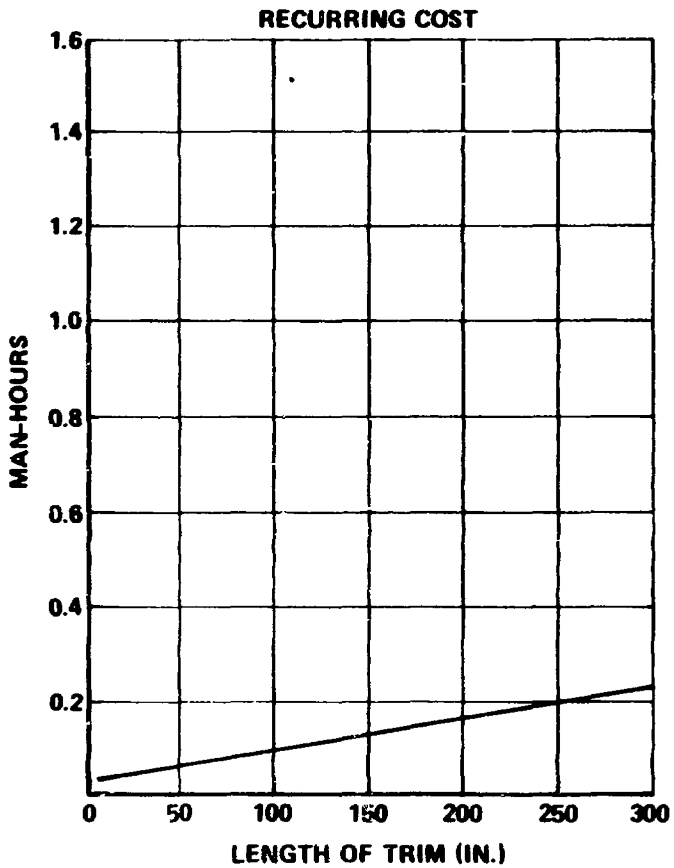
ALUMINUM, TITANIUM AND STEEL

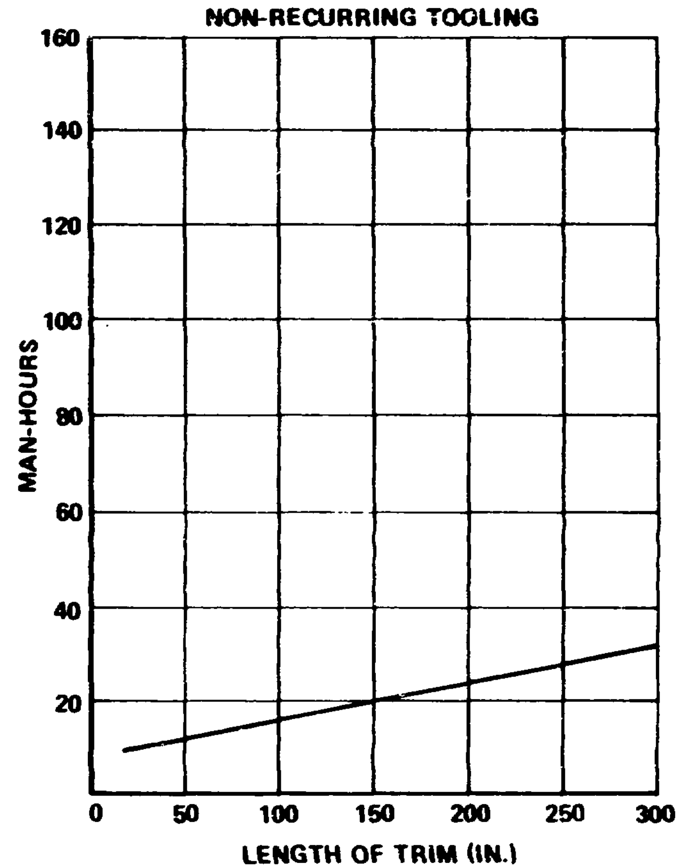


DICE-3


ALUMINUM STACK ROUT PRIOR TO FORMING
DICE-4
0.125" PART
0.062"
0.031"
MAN HOURS
0.5
0.4
0.3
0.2
0.1
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
PERIMETER (in.)

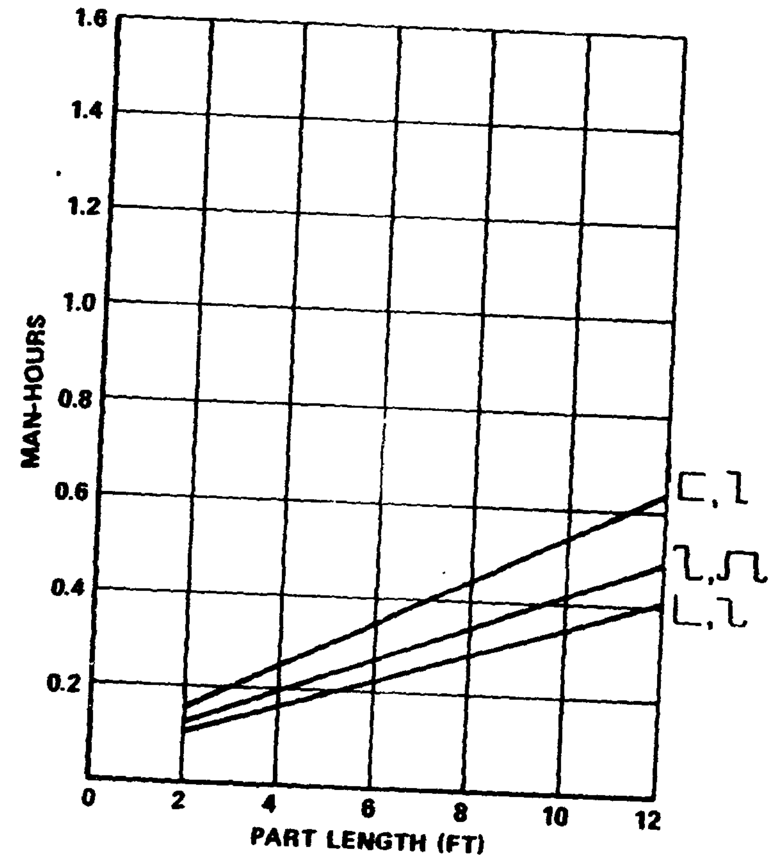
ALUMINUM LINEAL PARTS
TRIM AFTER FORMING





DICE-5

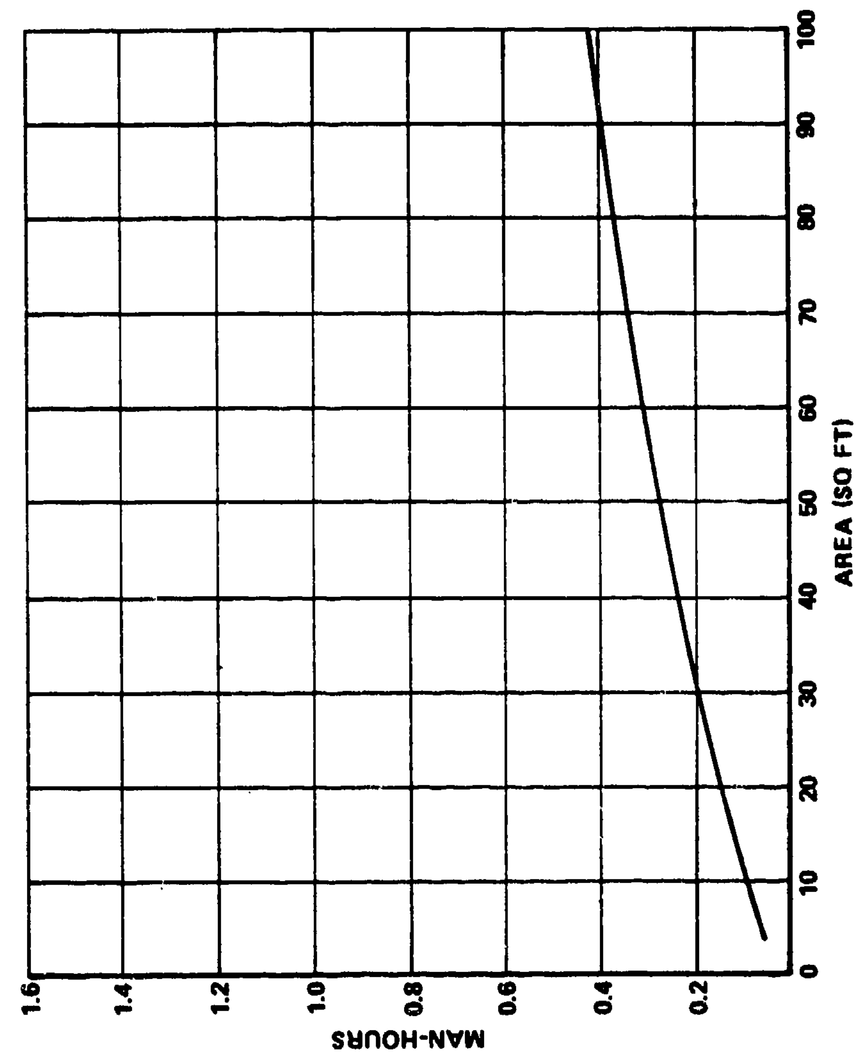
ALUMINUM, SOLUTION HEAT TREAT AND AGE TO T62



DICE-6

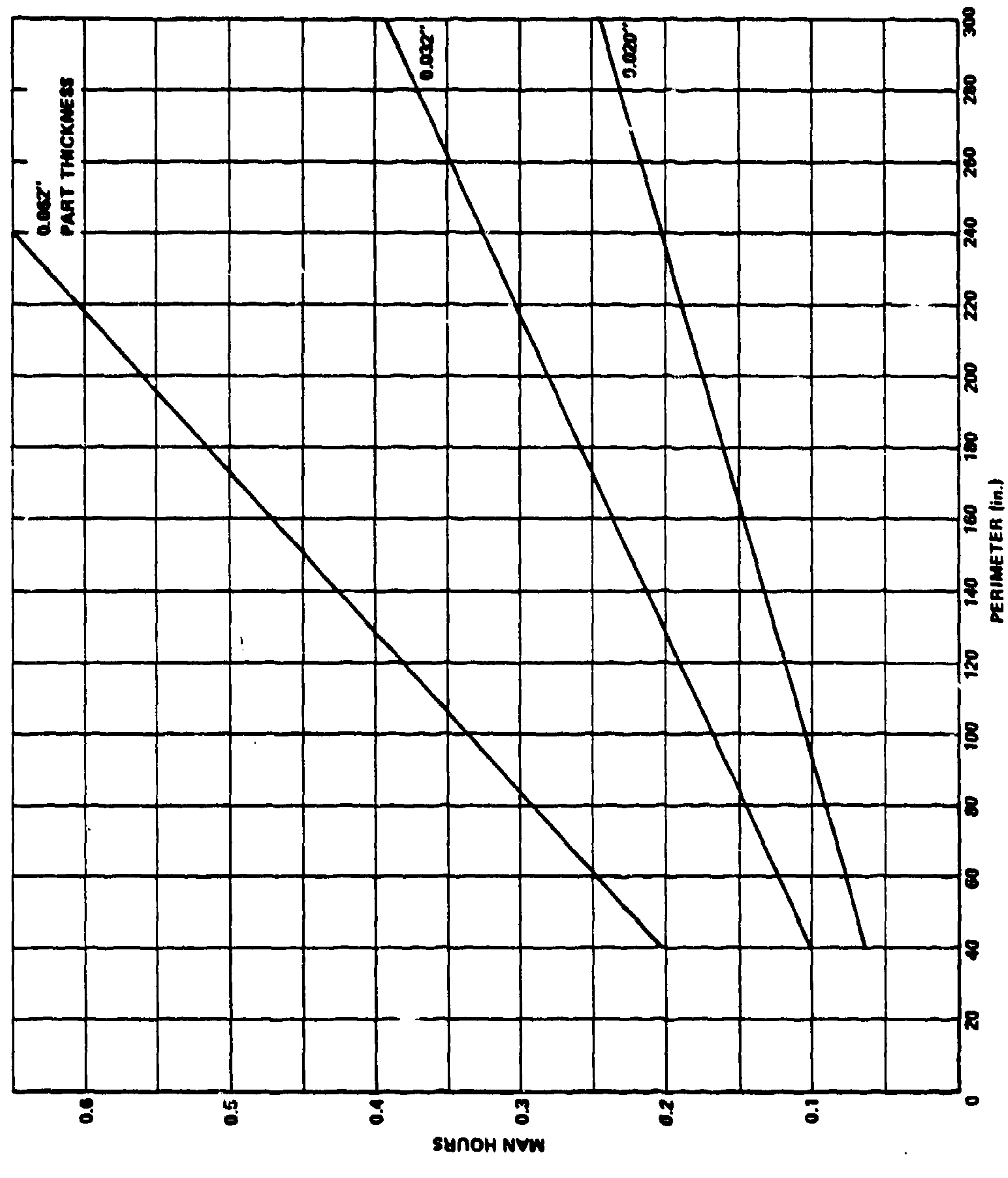
DICE-7

ALUMINUM, ARTIFICIAL AGE TO T81

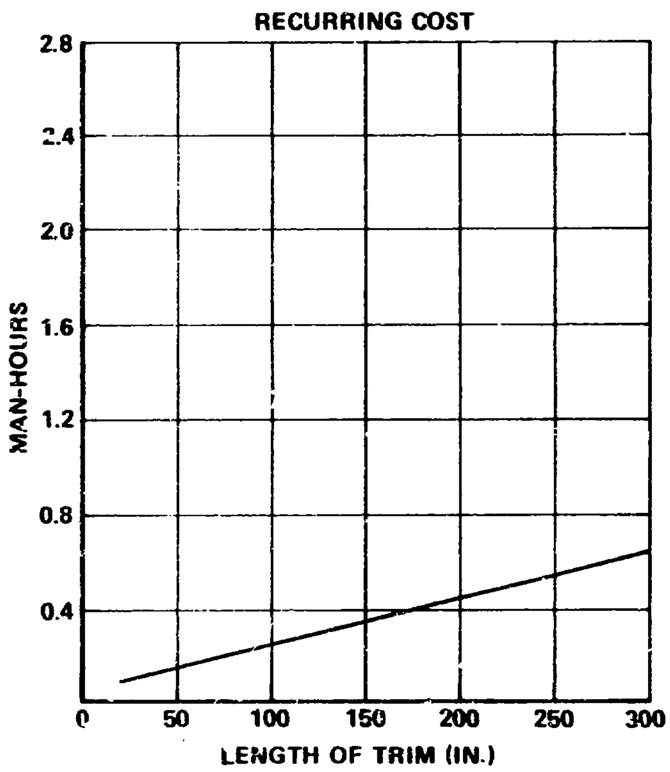


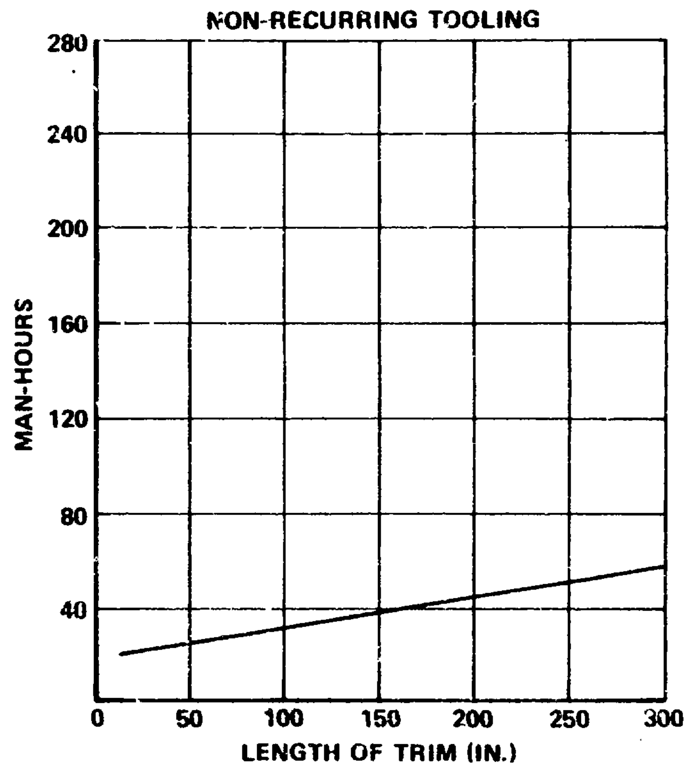
DICE-8

STEEL STACK MILL PRIOR TO FORMING



STEEL LINEAL PARTS
TRIM AFTER FORMING

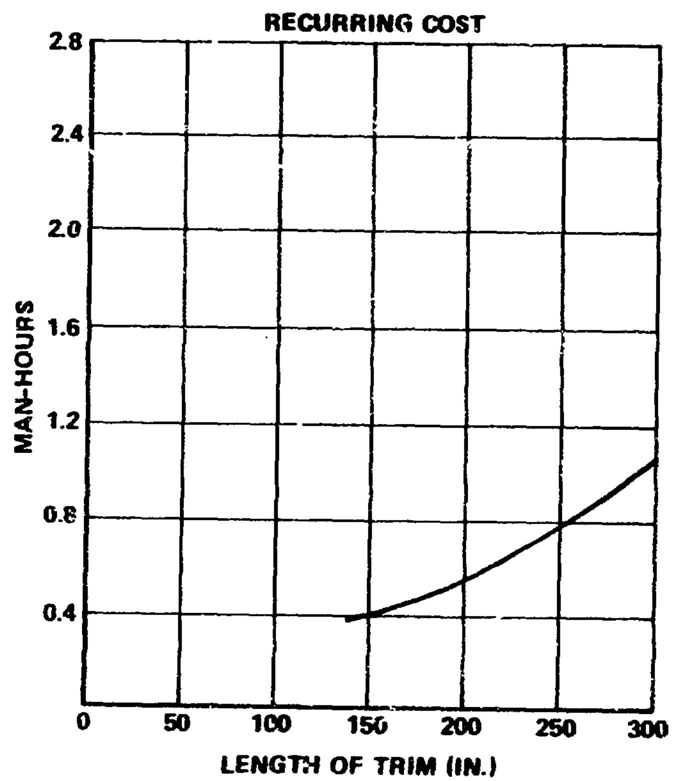


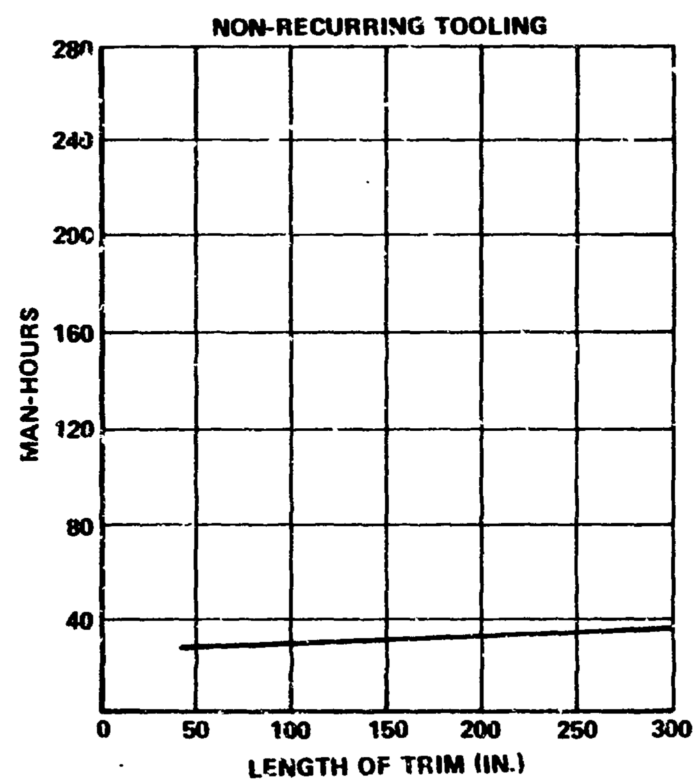


DICE-9

DICE—10

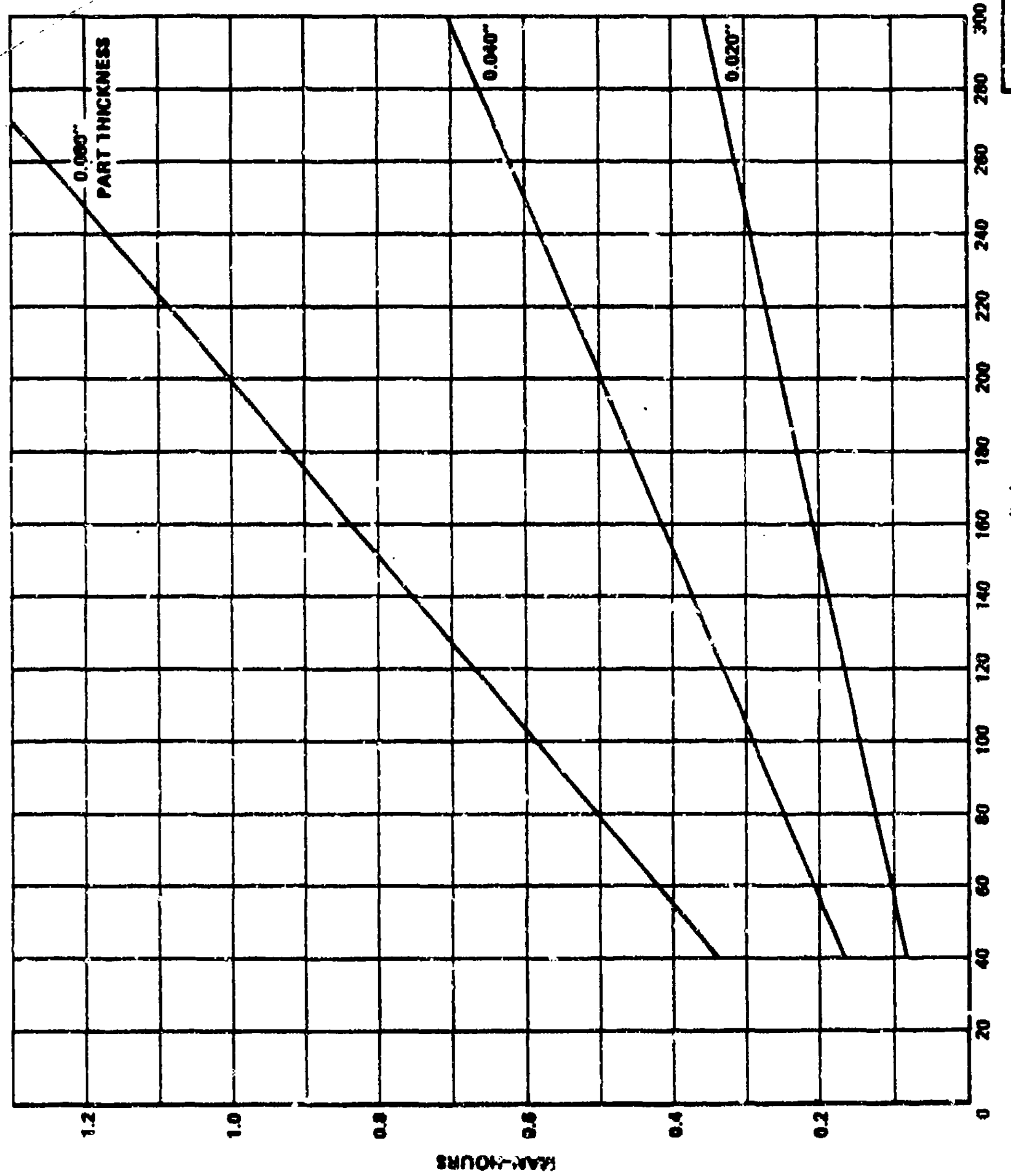
STEEL PANELS
TRIM AFTER FORMING



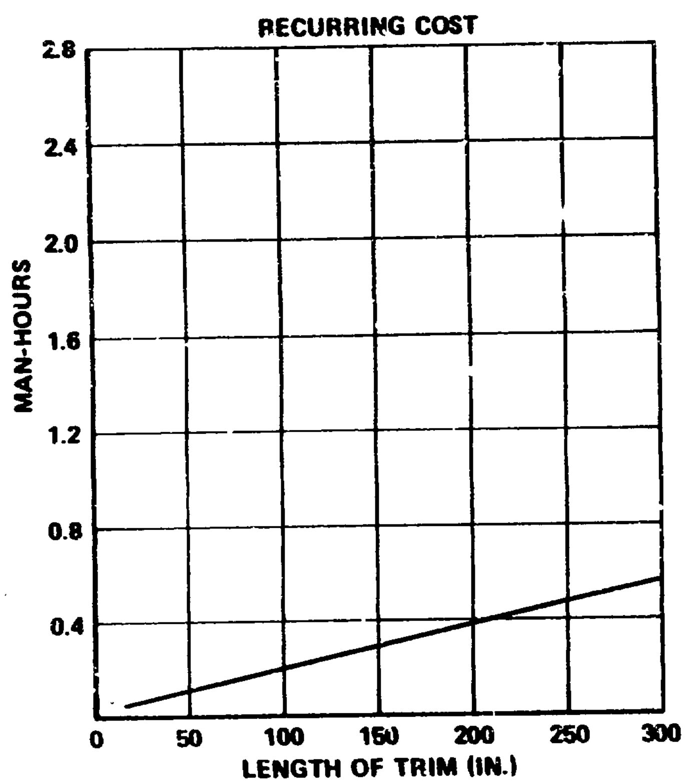


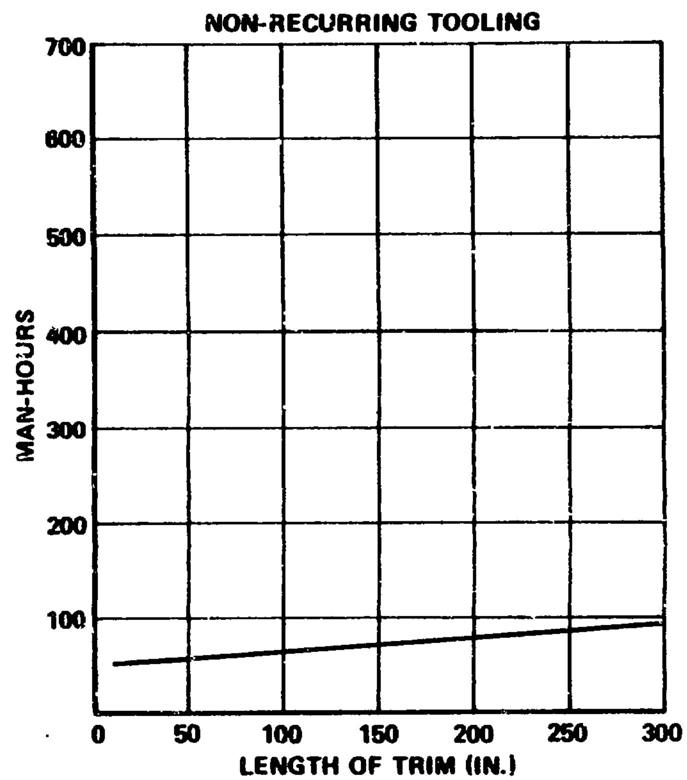
DICE-11

TITANIUM STACK MILL PRIOR TO FORMING



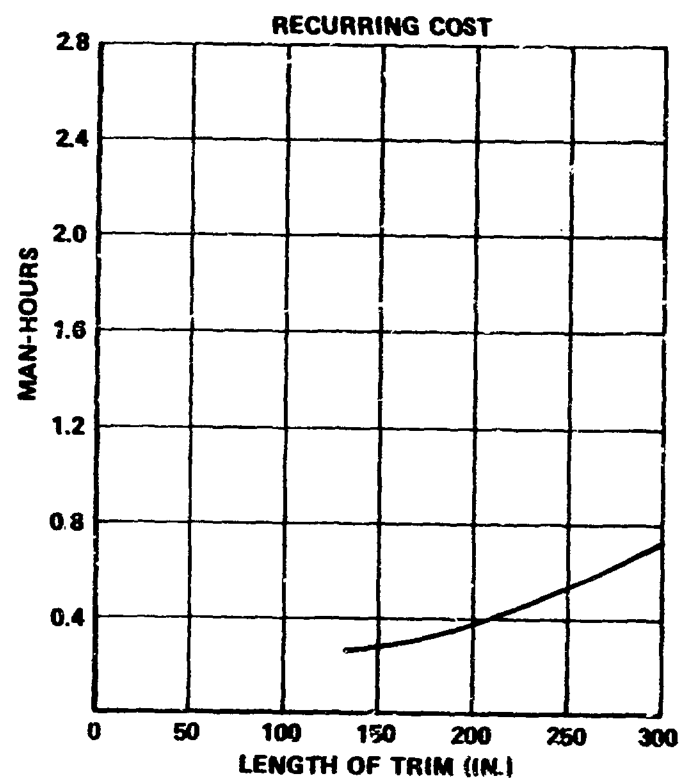
TITANIUM LINEAL PARTS
TRIM AFTER FORMING

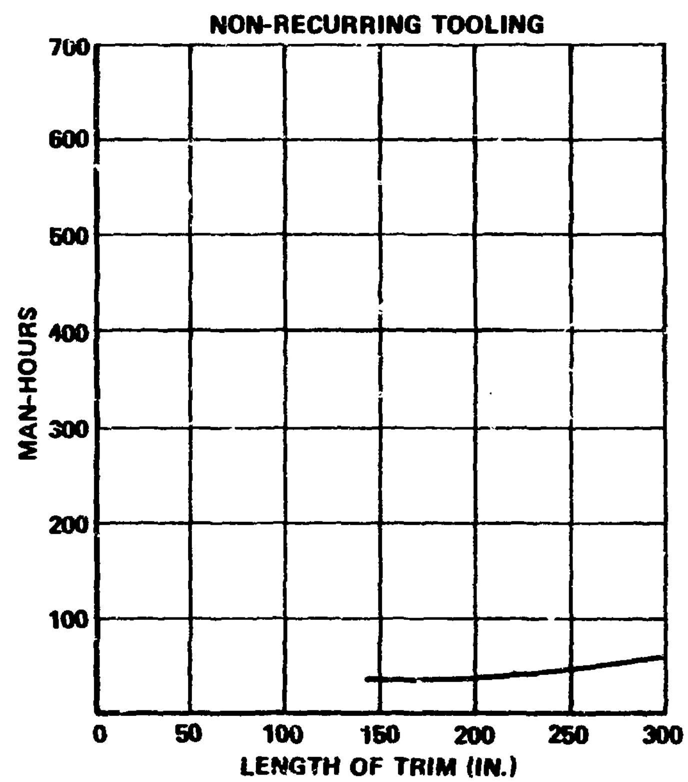




DICE-12

TITANIUM PANELS
TRIM AFTER FORMING





DICE-13

4.1.5.5 Formats for Comparison of Structural Sections Sheet-Metal Aerospace Discrete Parts

The following conditions apply to utilizing the formats in this section:

(1) Review ground rules in section for considerations and limitations.

(2) Consider step occurring in recurring cost man-hours for lineal shapes, at length of 6 feet, due to requirement of two persons for certain manufacturing operations.

(3) Bend radius limitations for titanium:
- At room temperature forming $\geq$ 5t
- At elevated temperature forming $\geq$ 2t.

(4) Materials selection: The user of the MC/DG is cautioned with respect to the range of factors that can also play an important role, besides manufacturing cost, in the selection of an airframe material. The airframe design requirements may include:
- Elevated temperatures
- Operation in corrosive environments
- Higher acquisition costs might be acceptable due to lower operations and maintenance costs.

All factors must be carefully considered by the designer prior to selecting a material or design concept based on manufacturing cost.

(5) Review definitions in Section 2.2. "Terms and Abbreviations". However, important terminology used on most formats are:

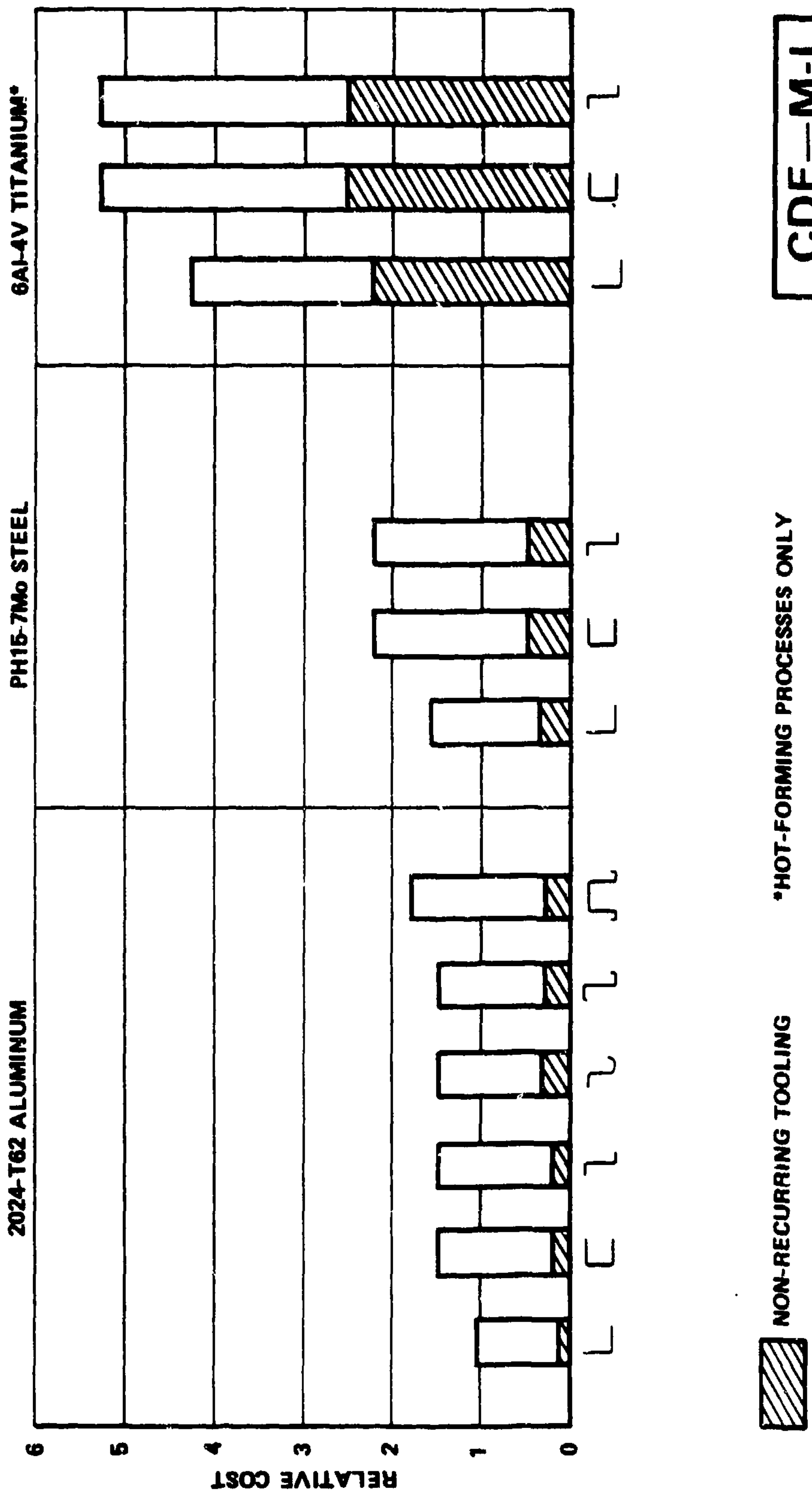
(a) Base Part: A detail part in its simplest form, i.e., without complexities such as heat treatment, cutouts, and joggles.

(b) Designer-Influenced Cost Elements (DICE): Includes joggles, cutouts, lightening holes, and special tolerances that add cost to the base part configuration. These additional costs are due to the increased fabrication operations and tooling required over the standard manufacturing method (SMM) for the base part.

(c) Detail or Discrete Parts: A distinct airframe structural part which may incorporate complexities, e.g., a base part plus DICE, ready for assembly to perform its required function in the airframe.

EFFECT OF CROSS-SECTION AND MATERIAL ON PART FORMING COST

STRAIGHT LINEAL SHAPES
RELATIVE RECURRING PLUS NON-RECURRING COST

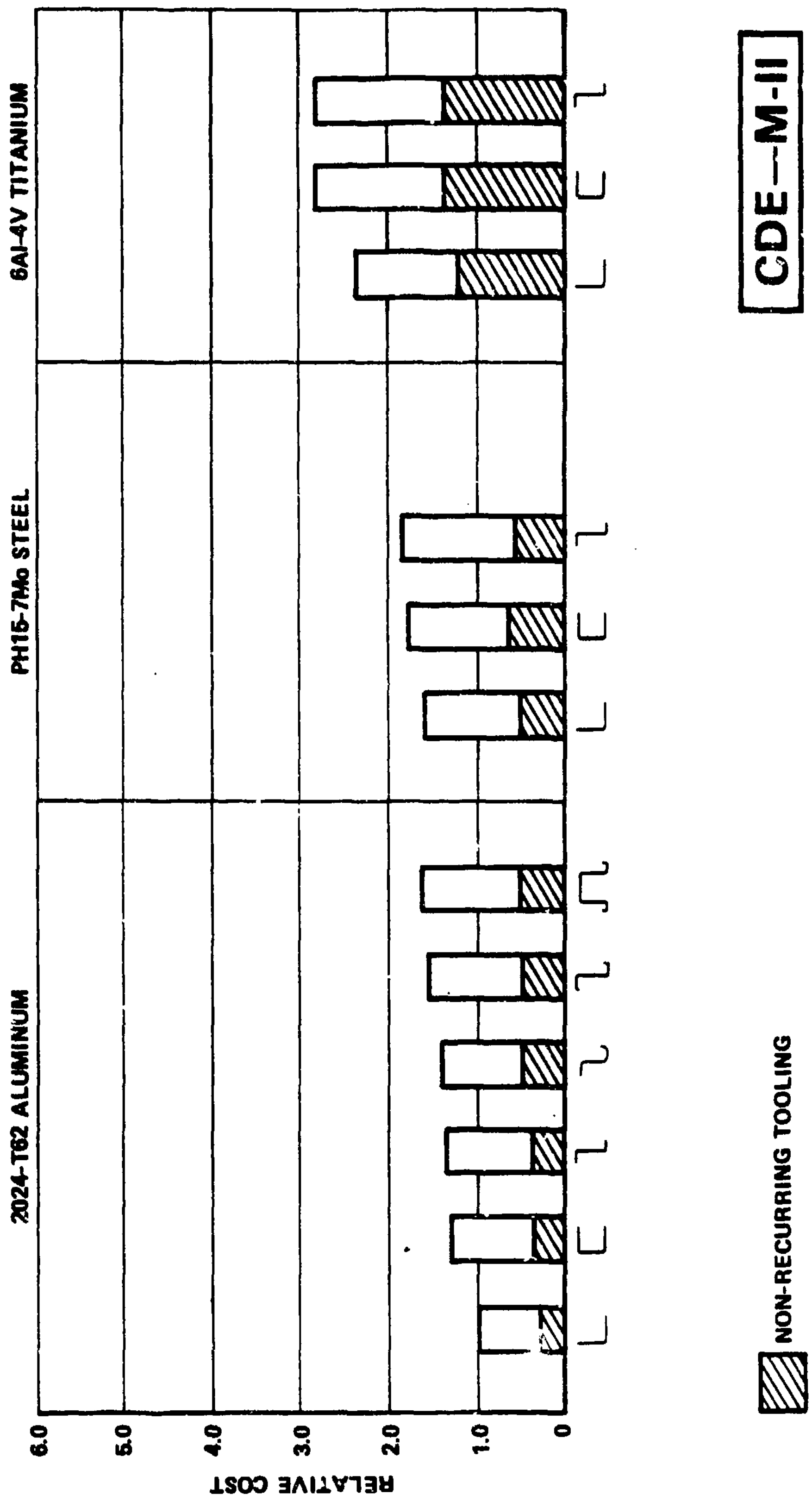


CDE—M-I

EFFECT OF CROSS-SECTION AND MATERIAL ON PART FORMING COST

CURVED LINEAL SHAPES

RELATIVE RECURRING PLUS NON-RECURRING COST



CDE—M-II

4.1.5.6 Formats for Comparison of Manufacturing Technologies for Sheet-Metal Discrete Parts

The following conditions apply to utilizing the formats in this section:

(1) Review ground rules in section for considerations and limitations.

(2) Consider step occurring in recurring cost man-hours for lineal shapes, at length of 6 feet, due to requirement of two persons for certain manufacturing operations.

(3) Bend radius limitations for titanium:
- At room temperature forming $\geq$ 5t
- At elevated temperature forming $\geq$ 2t.

(4) Materials selection: The user of the MC/DG is cautioned with respect to the range of factors that can also play an important role, besides manufacturing cost, in the selection of an airframe material. The airframe design requirements may include:
- Elevated temperatures
- Operation in corrosive environments
- Higher acquisition costs might be acceptable due to lower operations and maintenance costs.

All factors must be carefully considered by the designer prior to selecting a material or design concept based on manufacturing cost.

(5) Review definitions in Section 2.2 "Terms and Abbreviations". However, important terminology used on most formats are:

(a) Base Part: A detail part in its simplest form, i.e., without complexities such as heat treatment, cutouts, and joggles.

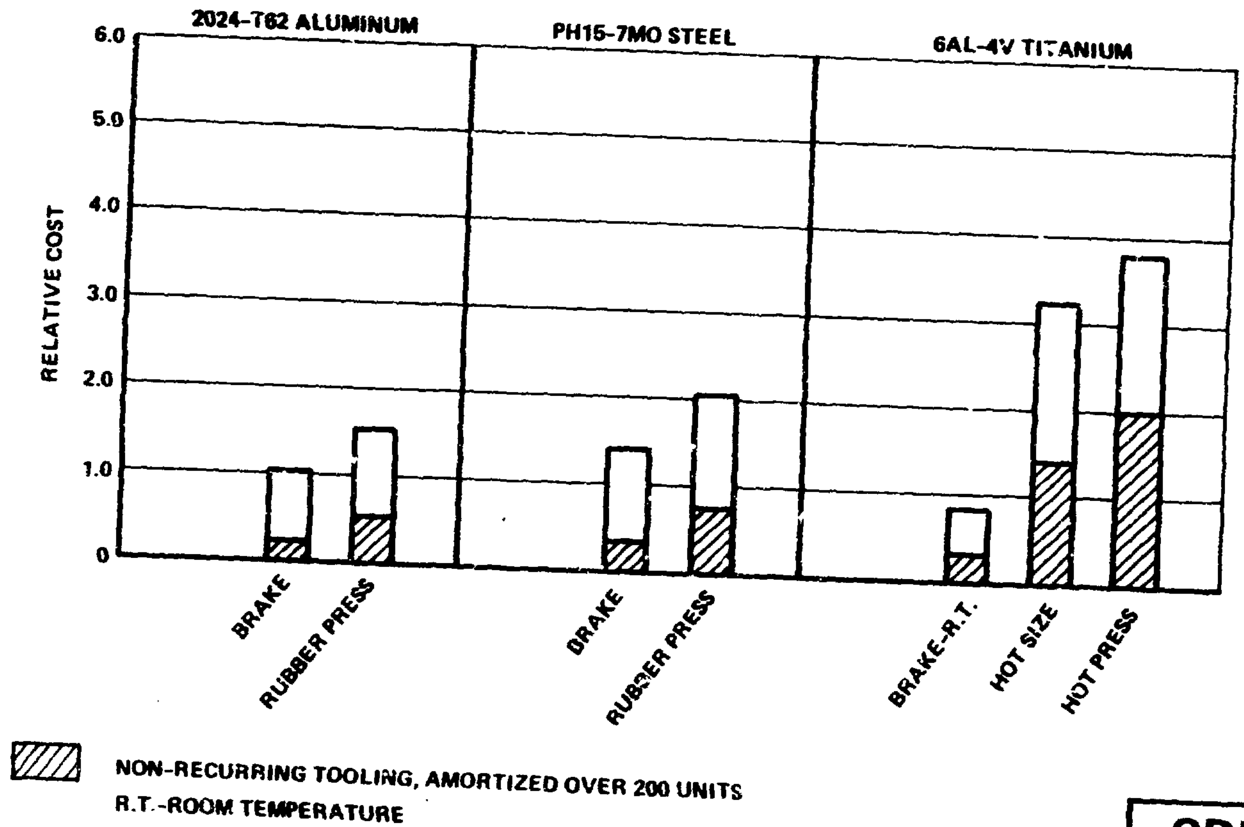
(b) Designer-Influenced Cost Elements (DICE): Includes joggles, cutouts, lightening holes, and special tolerances that add cost to the base part configuration. These additional costs are due to the increased fabrication operations and tooling required over the standard manufacturing method (SMM) for the base part.

(c) Detail or Discrete Parts: A distinct airframe structural part which may incorporate complexities, e.g., a base part plus DICE, ready for assembly to perform its required function in the airframe.

EFFECT OF FORMING PROCESS AND MATERIAL ON PART FORMING COST

STRAIGHT LINEAL SHAPES

RECURRING PLUS NON-RECURRING COSTS

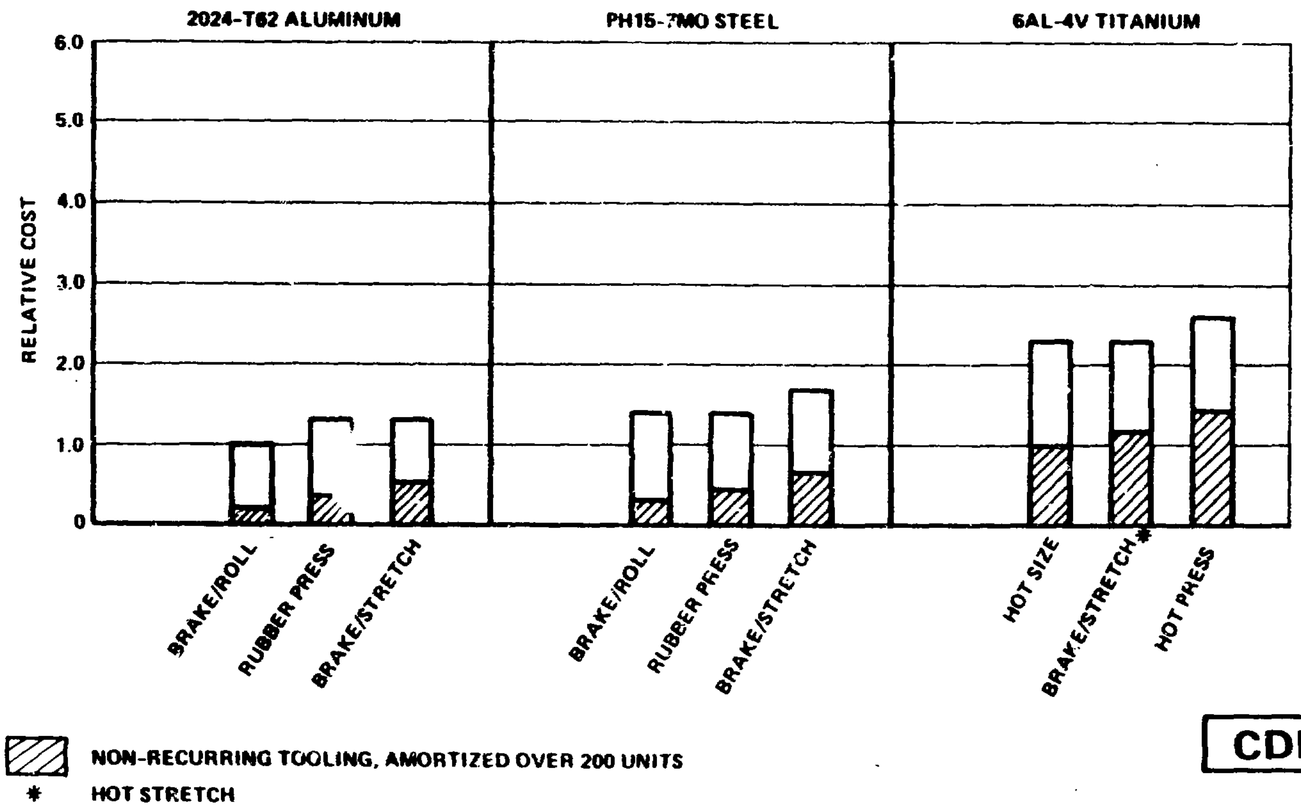


CDE—P-I

EFFECT OF FORMING PROCESS AND MATERIAL ON PART FORMING COST

CURVED LINEAL SHAPES

RECURRING PLUS NON-RECURRING COSTS



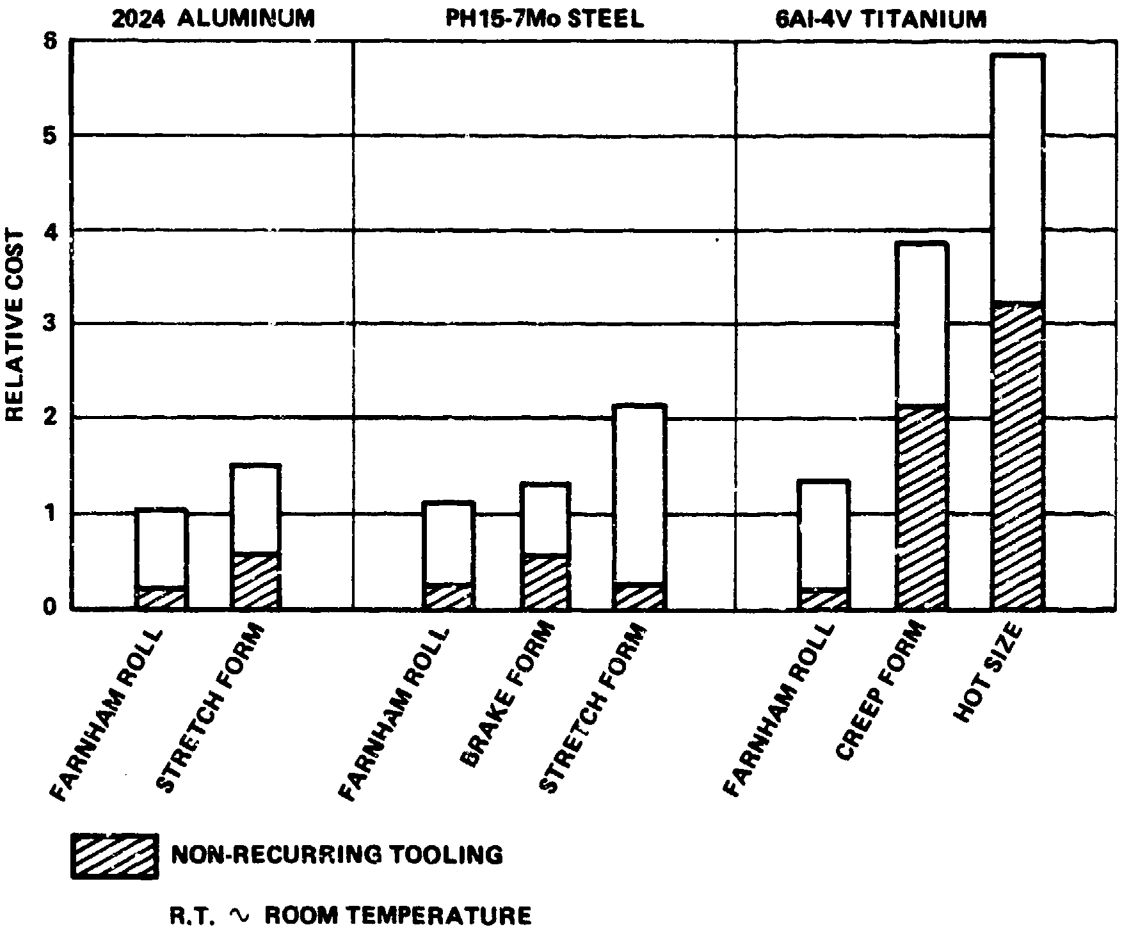
SEE GROUND RULES FOR LIMITATIONS AND CONDITIONS

CDE—P-II

EFFECT OF FORMING PROCESS AND MATERIAL ON PART FORMING COST

SINGLE CURVATURE SKIN

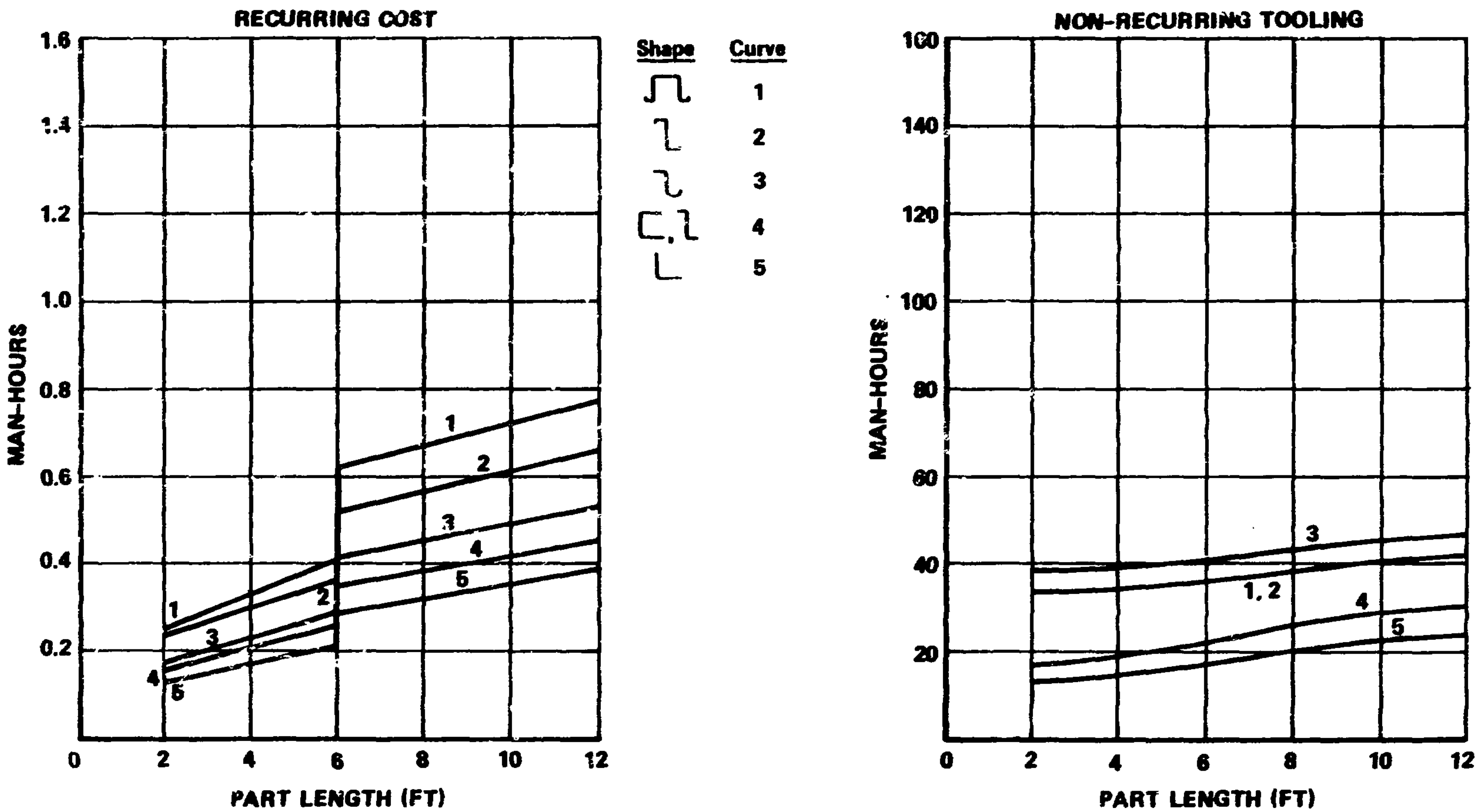
RECURRING PLUS NON-RECURRING COSTS, INCLUDING TRIM



CDE—P-III

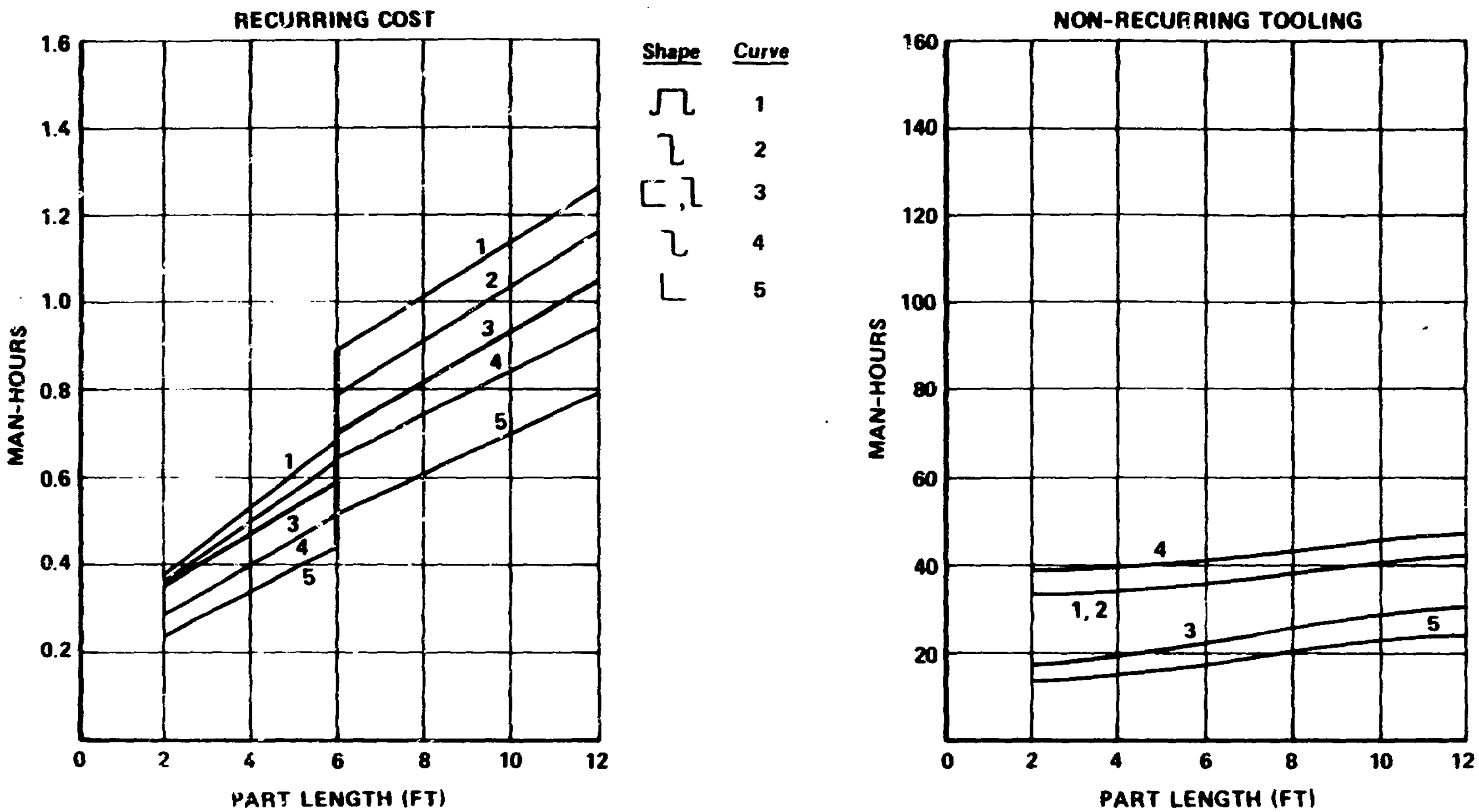
STRAIGHT ALUMINUM LINEAL SHAPES

BRAKE FORM



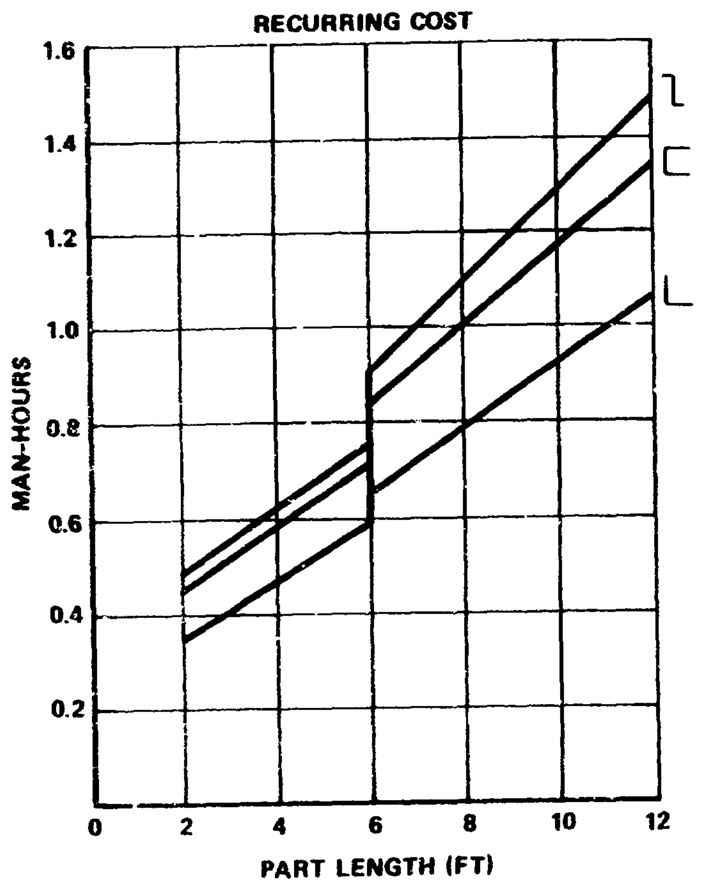
CED—M-1

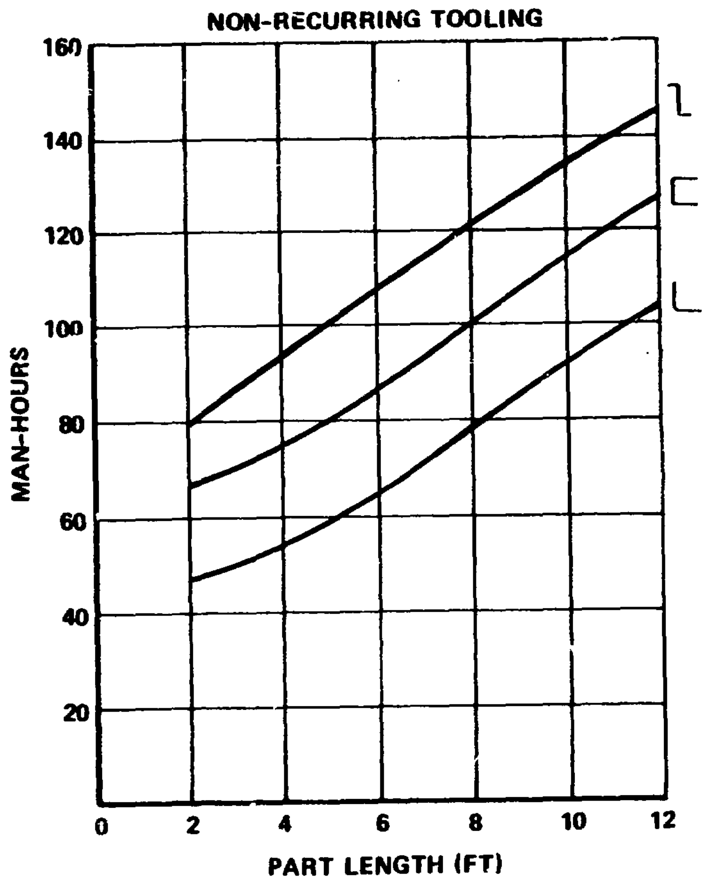
STRAIGHT ALUMINUM LINEAL SHAPES
BRAKE FORM
HEAT TREATED TO T62



CED—M-2

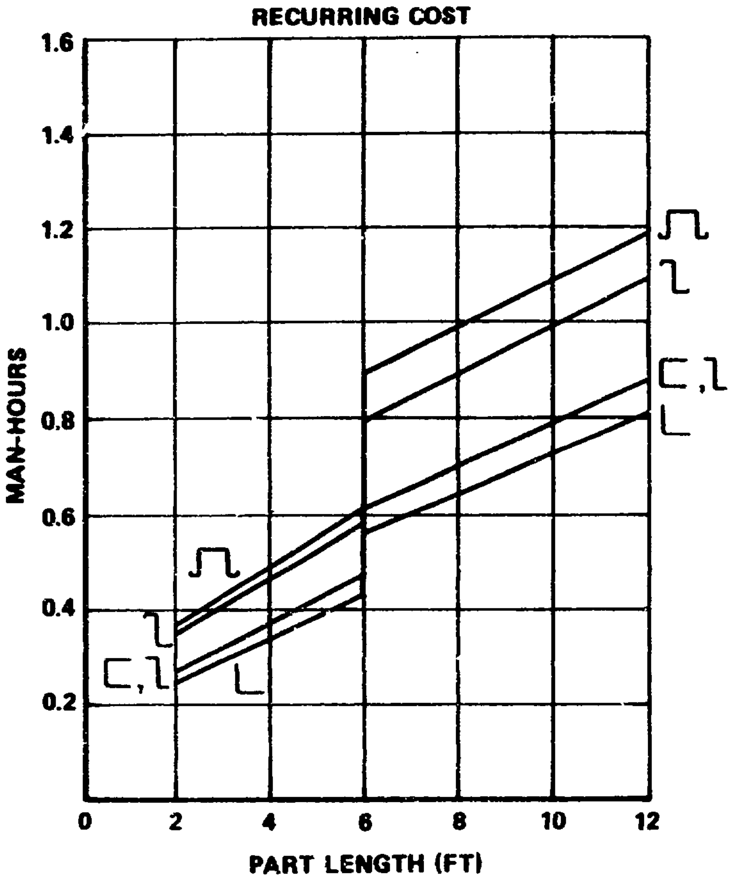
STRAIGHT AND CONTOURED, ALUMINUM LINEAL SHAPES
RUBBER PRESS

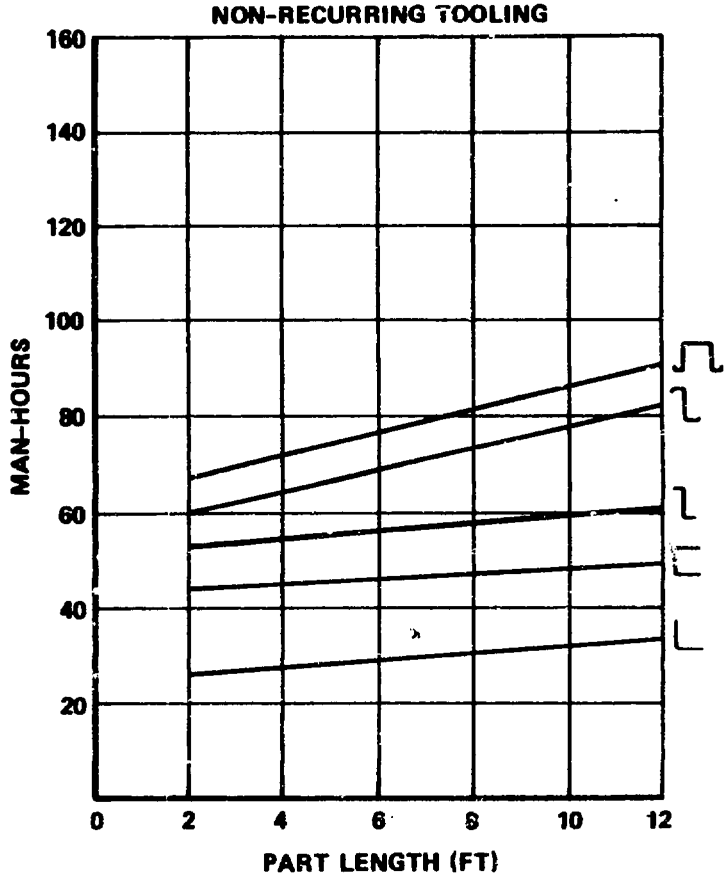




CED—M-3

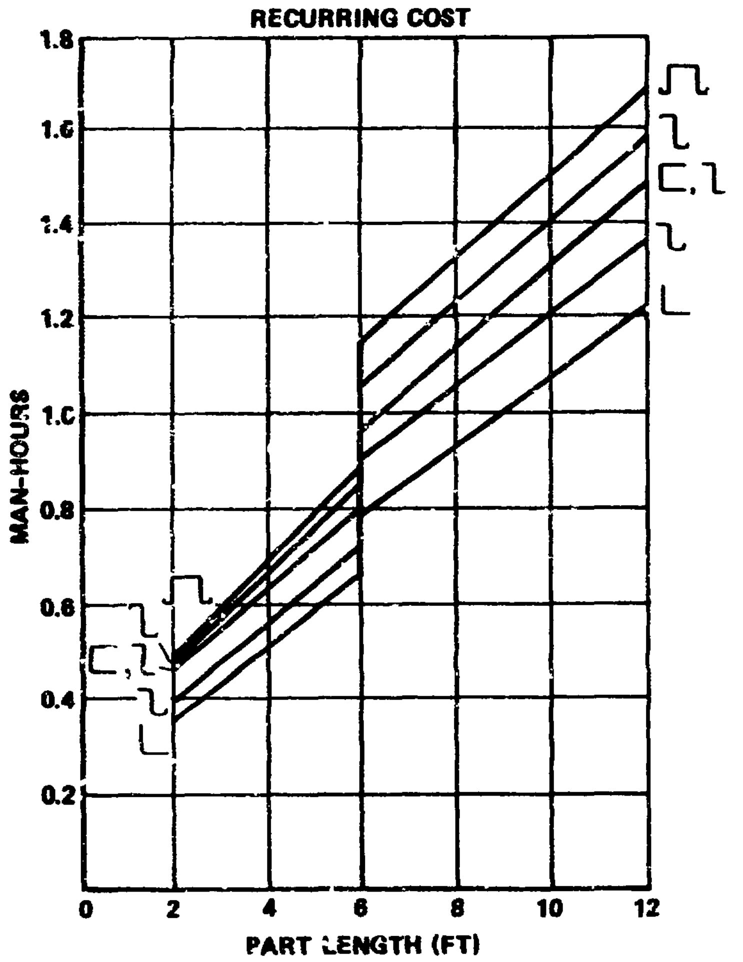
CONTOURED ALUMINUM LINEAL SHAPES
BRAKE AND ROLL

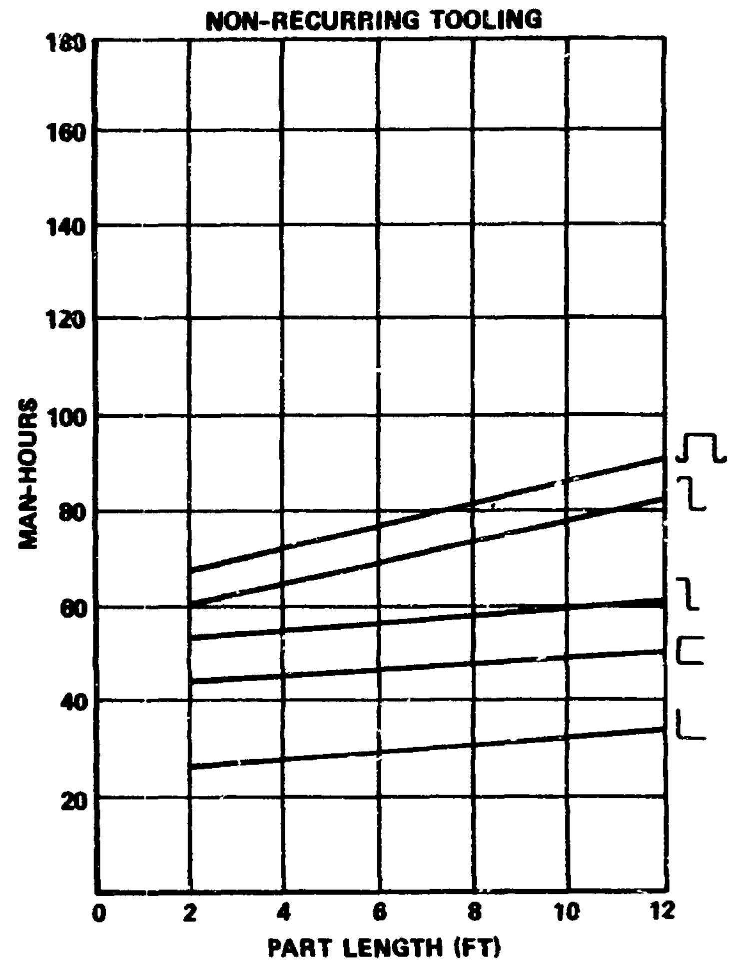




CED—M-4

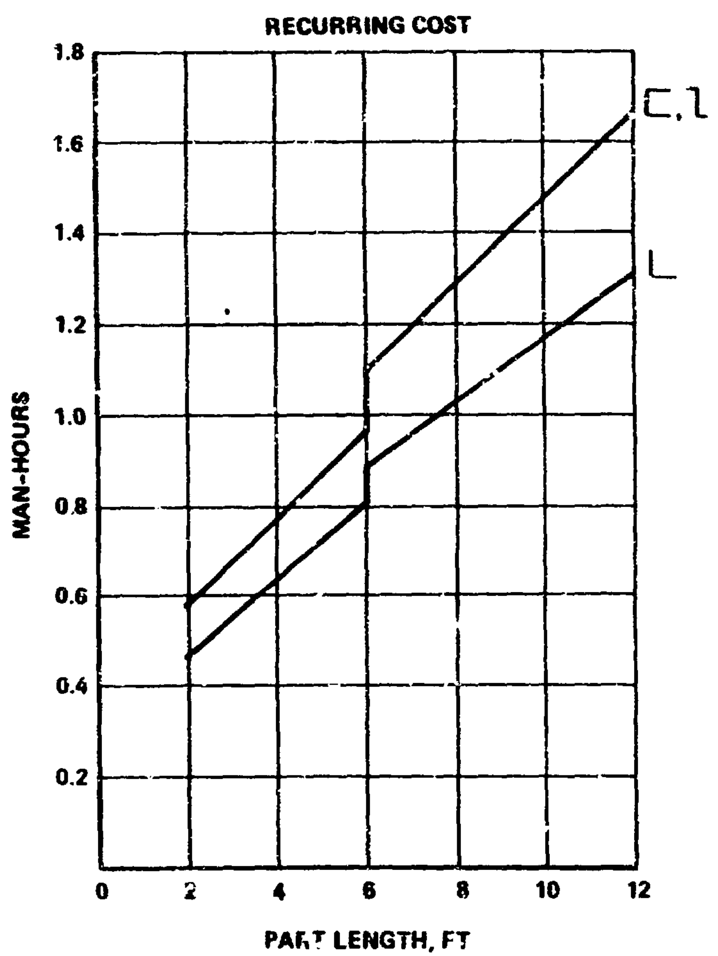
CONTOURED ALUMINUM LINEAL SHAPES
BRAKE AND ROLL
HEAT TREATED TO T62

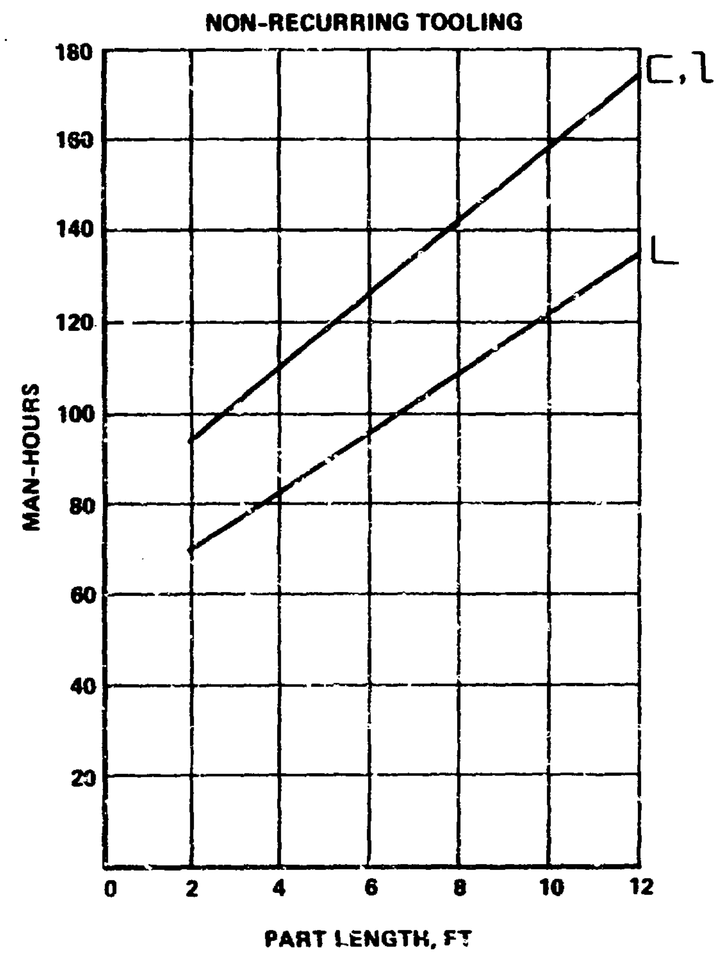




CED—M-5

CONTOURED ALUMINUM LINEAL SHAPES
BRAKE AND STRETCH
HEAT TREATED TO T62

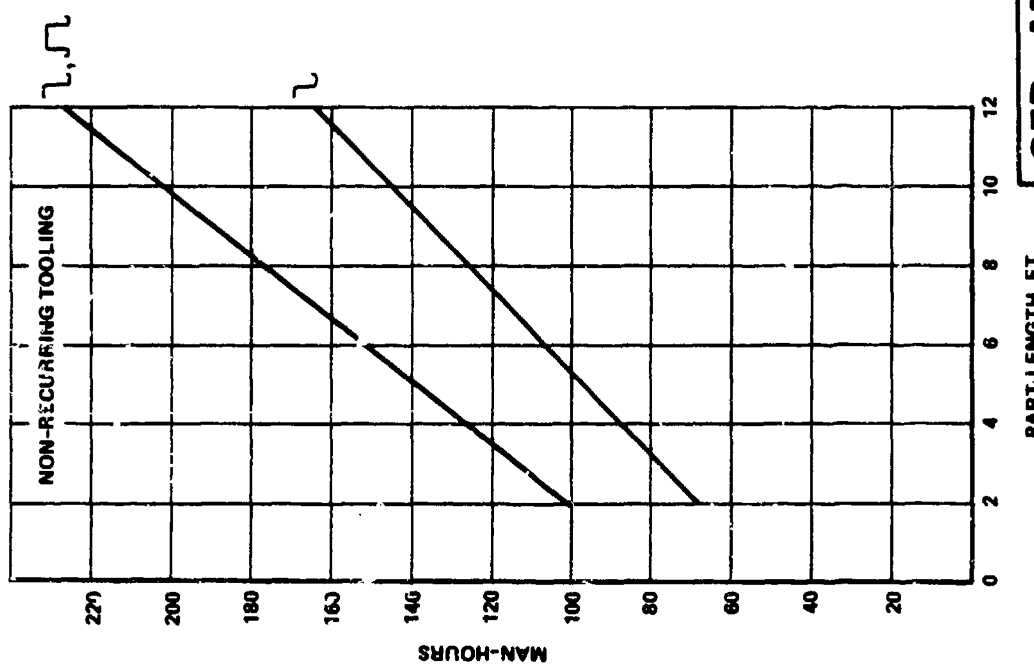


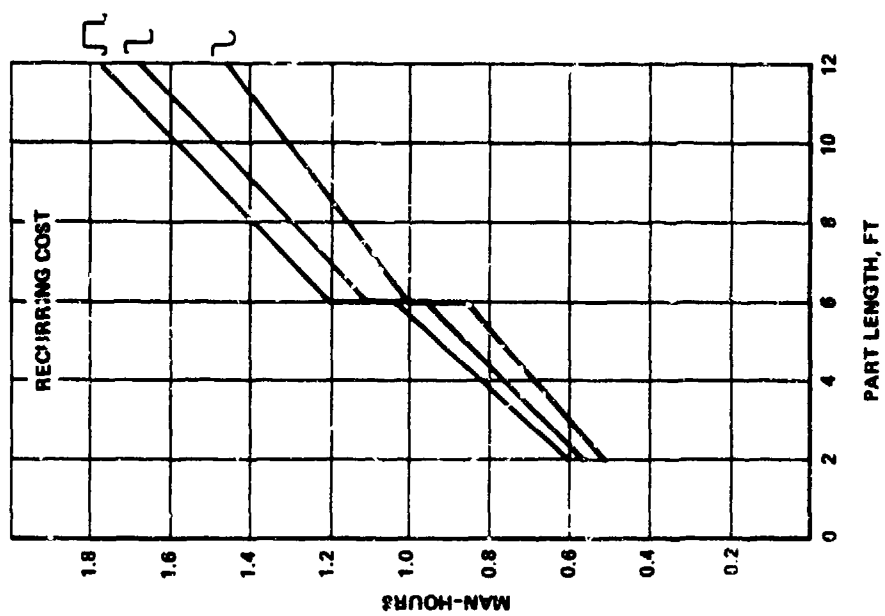


CED—M-6

CONTOURED ALUMINUM LINEAL SHAPES
BRAKE AND STRETCH
HEAT TREATED TO T62

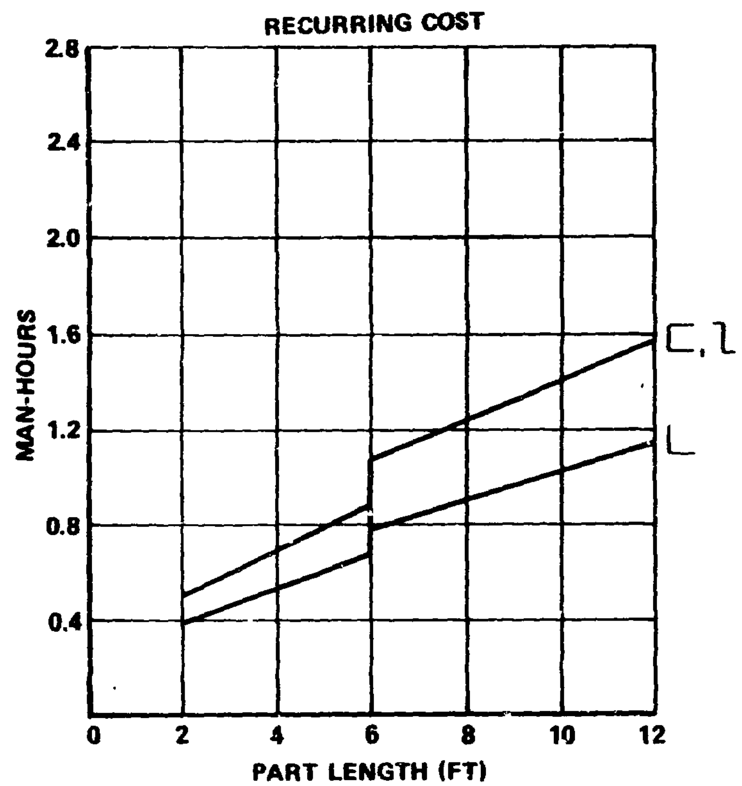
CED—M-7

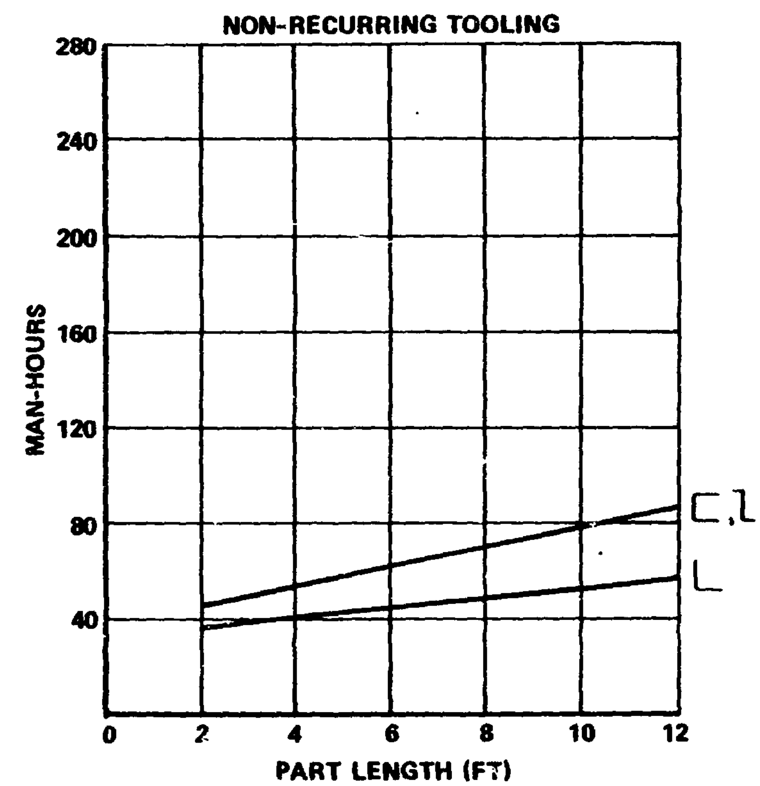




STRAIGHT STEEL LINEAL SHAPES

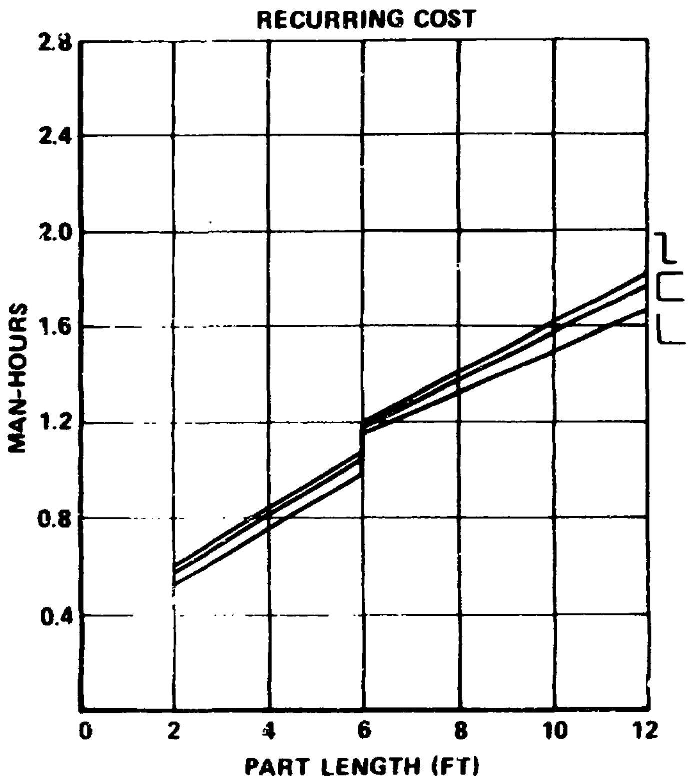
BRAKE FORM

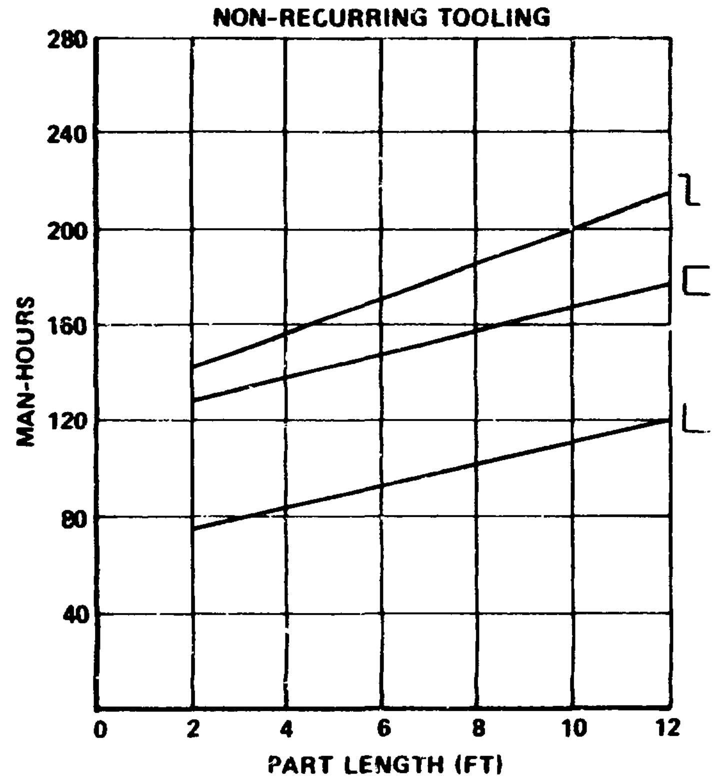




CED—M-8

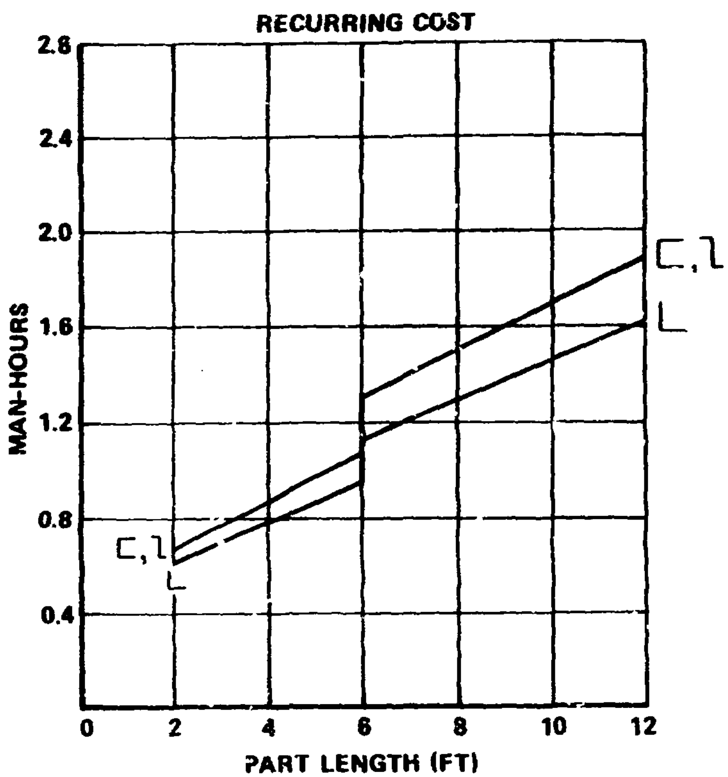
STRAIGHT AND CONTOURED STEEL LINEAL SHAPES
RUBBER PRESS

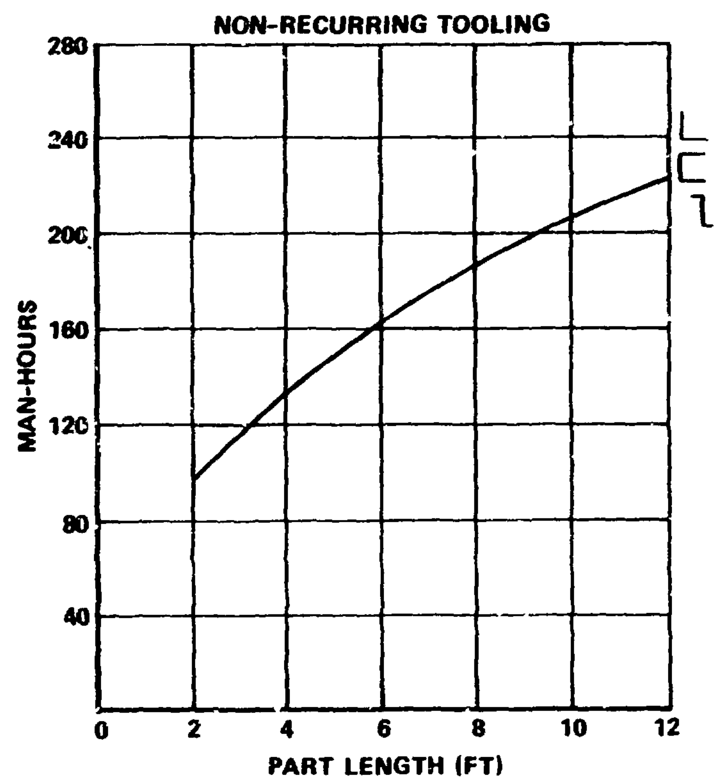




CED—M-9

CONTOURED STEEL LINEAL SHAPES
BRAKE AND STRETCH

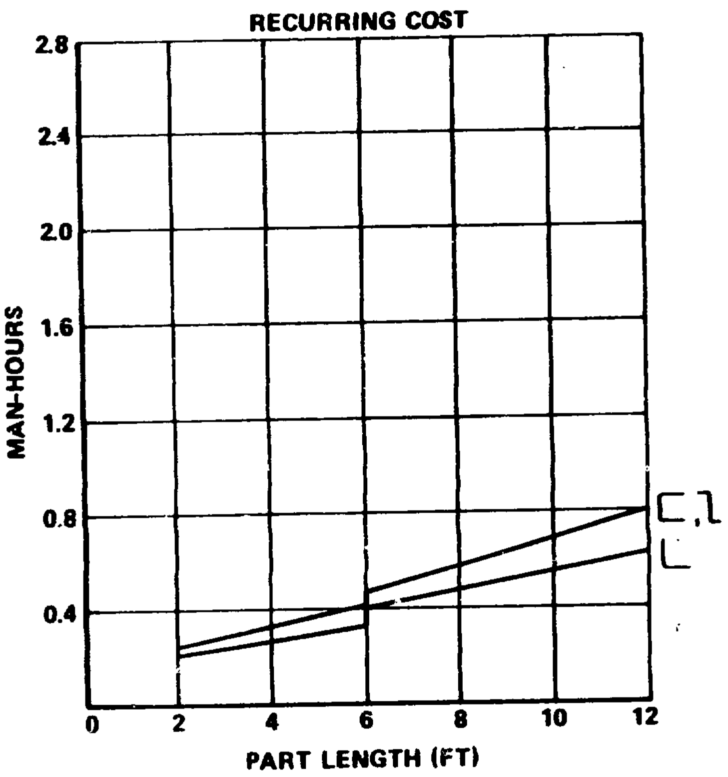


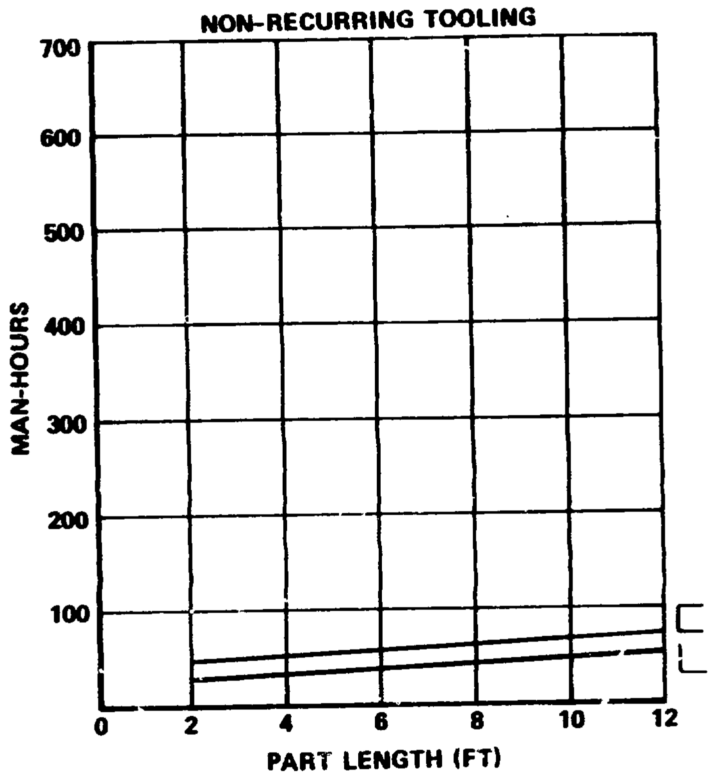


CED—M-10

STRAIGHT TITANIUM LINEAL SHAPES

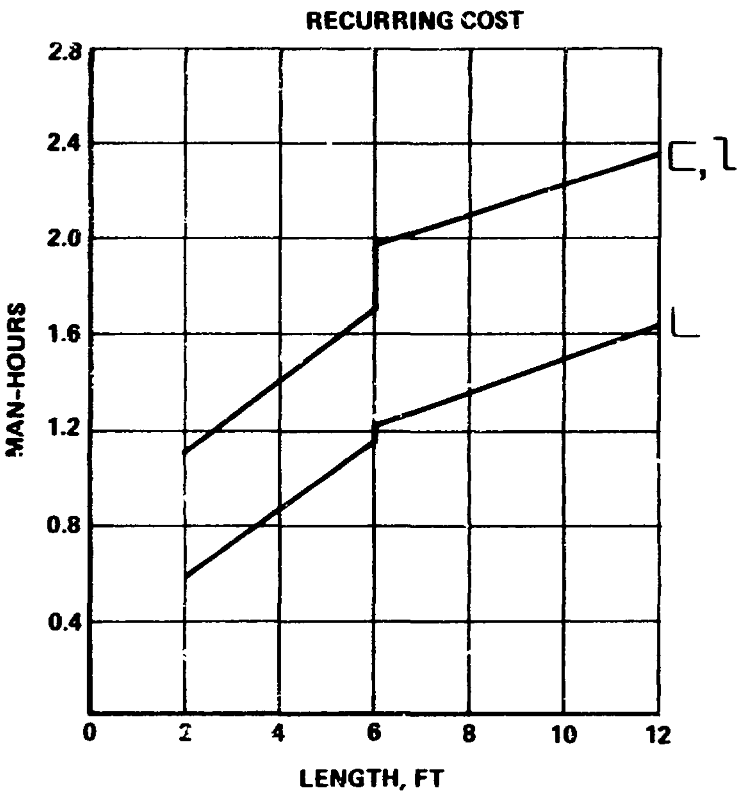
BRAKE FORM

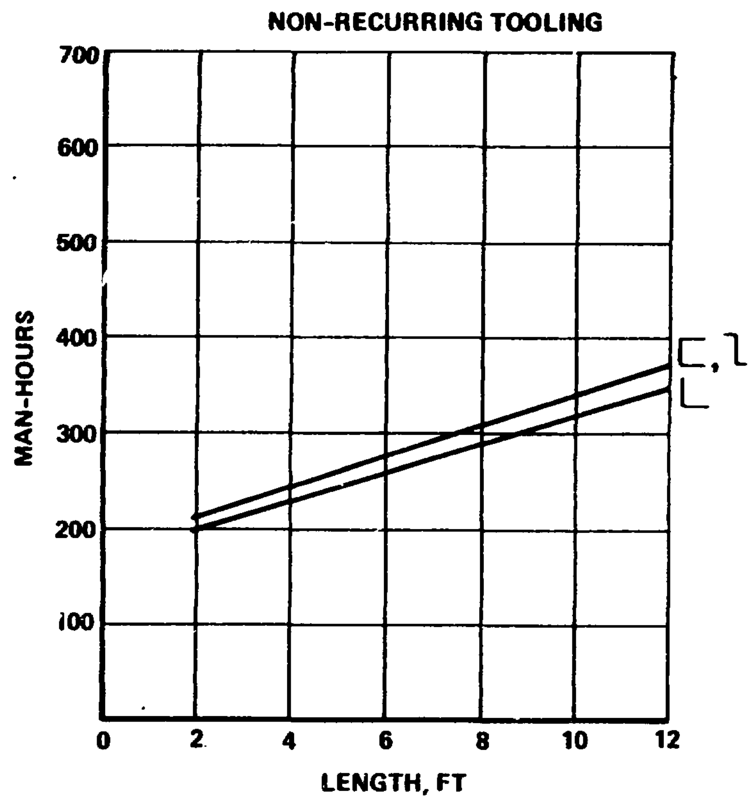




CED—M-11

STRAIGHT TITANIUM LINEAL SHAPES
PREFORM AND HOT SIZE

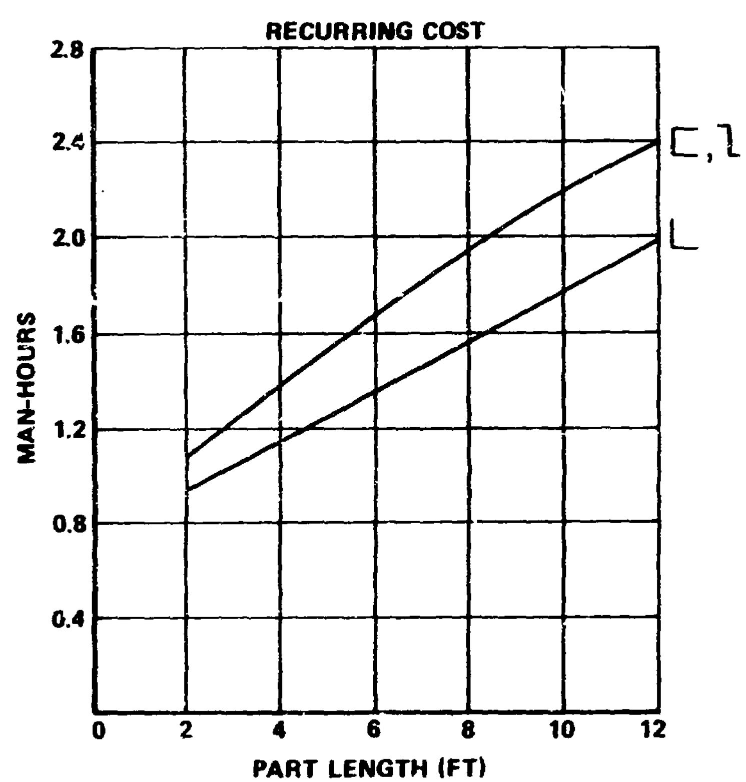


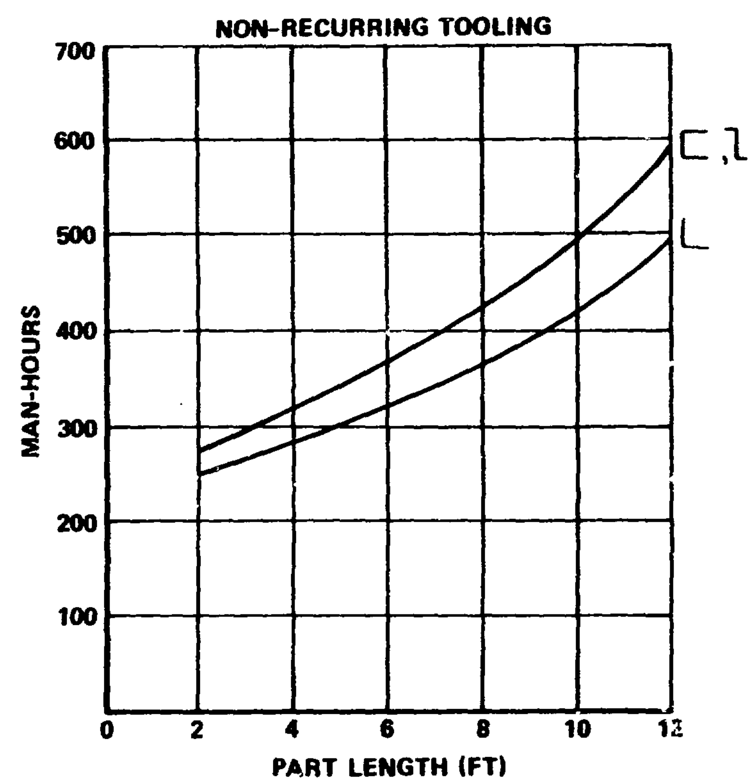


CED—M-12

STRAIGHT AND CONTOURED TITANIUM LINEAL SHAPES

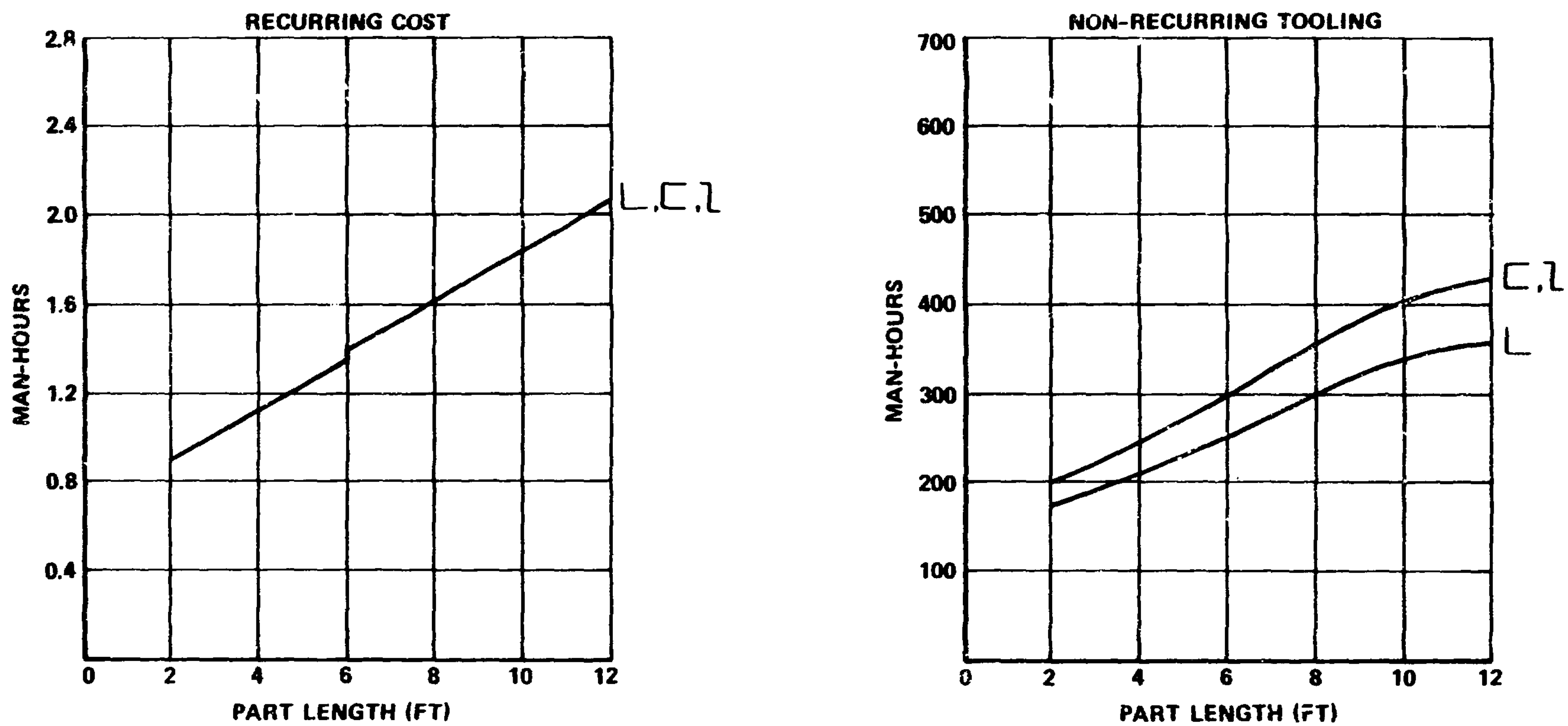
HOT PRESS





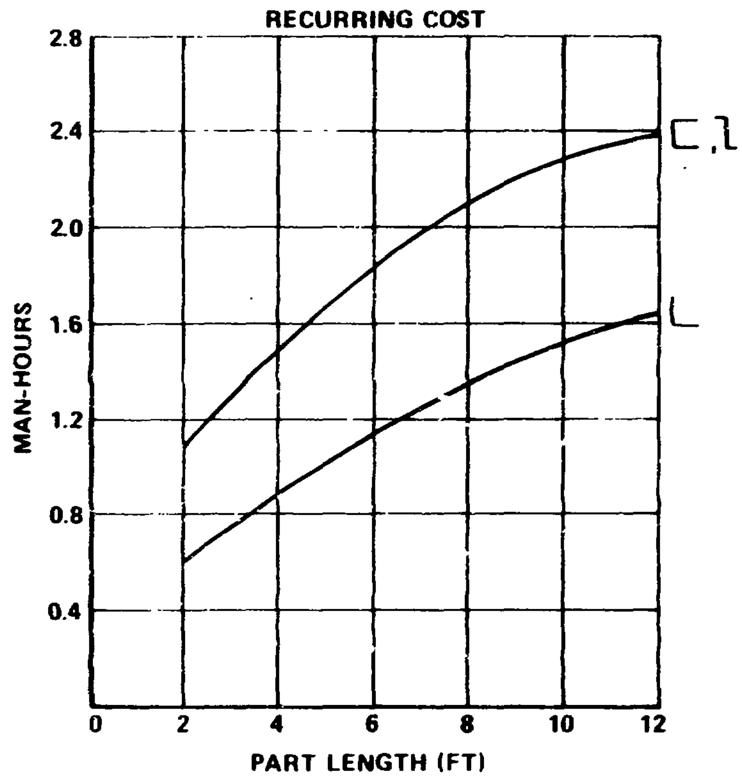
CED—M-13

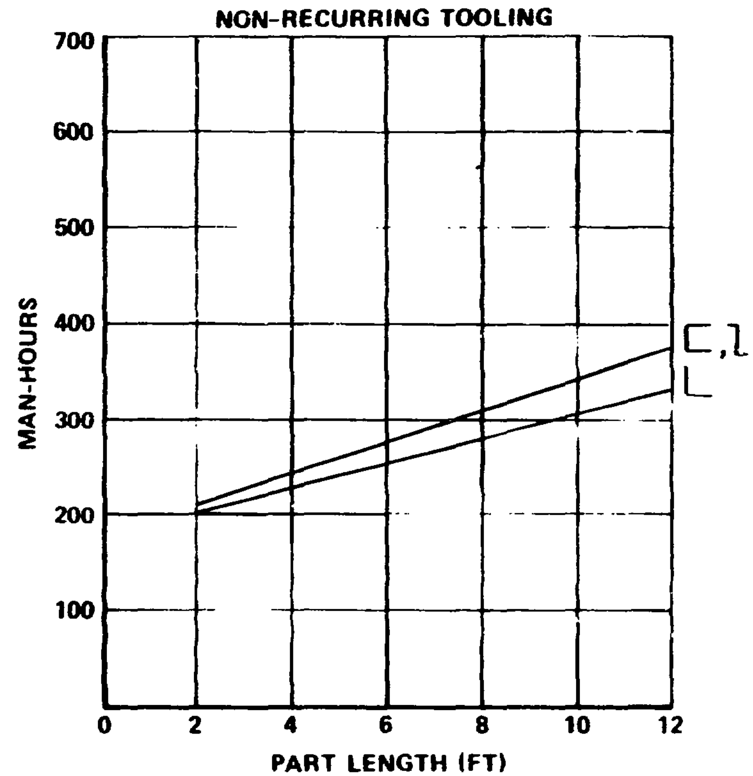
CONTOURED TITANIUM LINEAL SHAPES
ROOM TEMPERATURE BRAKE AND HOT STRETCH



CED—M-14

CONTOURED TITANIUM LINEAL SHAPES
PREFORM AND HOT SIZE





CED—M-15

4.1.6 Ground Rules for Sheet Metal Section

The following General and Detailed Ground Rules for the Sheet Metal Section were developed to establish the scope of the data required and to establish guidance to MC/DG application. Ground rules are necessary and important as they promote understanding, ensure consistency, uniformity, and accuracy in generating and integrating data into the formats.

4.1.6.1 General Ground Rules

The general ground rules are categorized under the following major groupings:

(a) Sheet Metal Discrete Parts
(b) Materials
(c) Manufacturing Methods
(d) Facilities
(e) Data Generation - Recurring Costs
(f) Data Generation - Nonrecurring Costs
(g) Support Function Modifiers.

(a) Sheet Metal Discrete Parts

(1) The sheet metal aerospace discrete parts selected are representative of common structural parts required for both small and large aircraft. The parts have been selected such that a base part forms the foundation which the designer can modify as required to achieve the desired discrete part or structural configuration. The discrete parts include stringers, longerons, frames, and panels representing elements of major airframe structural subassemblies.

(2) The discrate parts were selected, where possible, to develop data for more than one manufacturing method. The data thereby enables the designer, using the MC/DG, to determine the most cost-competitive manufacturing method in trade studies.

(3) The selected discrete parts were defined and dimensioned to adequately display the effect on part cost of DICE, e.g., heat treatment and lightening holes. Facility limitations were used in determining the dimension ranges for the discrete part considered.

(4) Support function modifiers were excluded but can be handled in the preferred way by the aerospace company using the MC/DG.

(b) Materials

(1) The alloys selected for the discrete parts were representative of the range of those more commonly used in the industry to enable a uniform data base to be established. The materials included were:
- Aluminum - 2024 sheet
- Titanium - 6Al-4V sheet
- Steel - PH15-7Mo sheet.

(2) Raw material costs for the parts were not included in the MC/DG formats but can be treated by the user at his discretion. However, the designer must be alerted and directed to include material costs wherever material costs are a cost driver such as with certain emerging materials.

(3) Material cost of nonrecurring tooling was not generally included, except when this cost impacts a design decision, for example, for manufacturing certain discrete parts in titanium and steel.

(c) Manufacturing Methods

(1) Only conventional manufacturing methods required to produce the sheet metal parts in the configurations selected were considered. No emerging manufacturing methods were evaluated.

(2) A production, in contrast to a prototype, environment was assumed for the sheet metal aerospace discrete parts.

(3) To generate an effective data base for each selected part, a factory operational sequence for each applicable manufacturing method was established reflecting the most economical means of fabrication. This standardized sequence was used by each team member to determine the part cost (man-hours).

(4) Tool families required to manufacture the various parts were identified on the data collection forms.

(d) Facilities

(1) Only standard manufacturing facilities, available to the airframe industry, were considered.

(e) Data Generation - Recurring Costs

(1) Recurring and nonrecurring man-hour data were generated for the complete process of parts fabrication and included all hands-on-factory direct labor operations from raw stock blank preparation through forming, heat treatment, priming, etc., to storage of the part in readiness for assembly into the airframe.

(2) The base-part cost (man-hours) was generated for each part. The base-part cost represented the sum of all standard hours associated with each part.

(3) DICE, requiring added operations, were treated as separate cost elements and, therefore, not included in the base-part cost.

(4) The quantity for which the base-part cost was determined was unit 200 and was based on team member learning curves.

(5) Cost data were presented in man-hours.

(6) To demonstrate the cost impact of setup costs, lot releases of 5, 10, 25, and 50 parts were evaluated. However, the values plotted on the MC/DG formats were only for lot size 25.

(7) Setup time (man-hours) is the total setup time required to complete the part. The setup time was amortized over the lot sizes and added to run times to obtain the base-part cost (man-hours).

(8) Recurring tooling costs (tool maintenance, planning, etc.) were not included.

(9) The data submitted to BCL were the base-part cost (man-hours) plus the costs (man-hours) of DICE associated with the discrete part design.

(10) In developing cost data for parts, each participating company utilized its own proprietary learning curves.

(11) The part cost (man-hours), as derived by each airframe company, was normalized by BCL to reflect an industry team average value for each sheet metal discrete part and range of dimensions.

(12) For proprietary reasons, realization factors (including PF&D), standard hours, and other business sensitive information employed at team member companies are not included in the analysis, or on the data sheets or MC/DG formats.

(13) No data provided by any team member are disclosed to other team members, agencies, or to the public without the expressed approval of the team member.

(f) Data Generation - Nonrecurring Costs

(1) Tool fabrication costs were generated for each part type. In addition, tool design and tool planning costs were evaluated with respect to their impact, to determine whether they should be included or omitted for the three material types.

(2) The cost of production tooling, if included, was restricted to contract or project tools only, for presentation in the MC/DG.

(3) Nonrecurring tooling costs (NRTC) generated by the team companies were normalized by BCL for presentation in the MC/DG.

(g) Support Function Modifiers

(1) Additional efforts other than factory labor, such as quality control and assurance and manufacturing engineering, were excluded from the part cost data supplied to BCL. These modifiers may be included later by the MC/DG users at airframe companies.

4.1.6.2 Detailed Ground Rules

The detailed ground rules are categorized under the following major groupings:

(a) Materials
(b) Gages (Thicknesses)
(c) Tolerances
(d) Discrete Parts
(e) Manufacturing Methods
(f) Facilities
(g) Contract Tooling.

(a) Materials

(1) The materials selected for sheet metal discrete parts are:
- Aluminum - 2024
- Titanium (annealed) - 6Al-4V
- Steel (annealed) - PH15-7Mo.

(2) Treatment required for any of these materials to increase physical properties or to improve formability are indicated on the part sketches, data collection forms, and formats.

(b) Gages (Thicknesses)

(1) Part thickness in each material type was:

- Aluminum: 0.063 inch
- Titanium: 0.040 inch
- Steel: 0.032 inch.

(c) Tolerances

(1) Parts were assumed to be formed using standard bend radii as dictated by the material type and thickness.

(2) Parts were assumed to be manufactured to a tolerance of ± 0.030 inch. The cost impact of tighter or more relaxed tolerances was addressed as a design complexity.

(d) Discrete Parts

(1) Drawings of the sheet metal aerospace discrete parts showing configurations, dimensions, joggles, holes, trim, heat treatment, etc., were prepared so that each team member may estimate base standard hours in a consistent manner.

(2) The cross-sectional dimensions of the lineal shapes corresponded to a maximum envelope of 6 inches diameter.

(3) The operational sequence necessary to produce each part, as required by the detail drawings, included every operation required to fabricate the part by the manufacturing method being evaluated, i.e., from the blank to completion ready for the storeroom and assembly into the airframe.

(4) To facilitate trade-off studies, the discrete parts and MC/DG formats indicate any thermal and/or chemical processing required such as heat treatment and anodizing, respectively, and also painting, prior to assembly, as specified on the detail drawing.

(e) Manufacturing Methods

(1) Forming methods used to fabricate the respective parts were specified on Part Size Matrices accompanying each drawing and on the Data Collection Forms.

(2) Where more than one manufacturing technology were candidates to fabricate a discrete part, data were generated for each method to reveal the comparative cost relationships to the designer.

(f) Facilities

(1) The types of forming equipment utilized in the fabrication of the parts were those listed in the Part Size Matrix accompanying each discrete part drawing.

(g) Contract Tooling

(1) Because of nonuniformity of tool nomenclature, each team member company indicated, on the Data Collection Forms, the tool family required to fabricate each discrete part. The nomenclature shown on the forms was supplemented with information providing a complete tool description, i.e., Drill Press Fixture (DPF).

(2) Tools included were those required to manufacture the tools, as well as those to make and check the parts, i.e., production check tools.

(3) The average hours per tool type, individual tool estimate, etc., were determined in accordance with each team member's standard procedures for determining cost.

4.2 Mechanically Fastened Assembly Section

This section contains format selection aids, identification of the types of parts analyzed for data to determine the manufacturing man-hour data, examples of how the data are utilized in airframe design and a set of mechanically fastened assembly formats. These formats include cost-driver effects (CDE), cost-estimating data (CED), and designer-influenced cost elements (DICE).

4.2.1 Format Selection Aids

Format selection aids are presented to provide the user with a building-block approach to determine manufacturing cost data for alternative designs or processes. The designer can review the format selection trees and identify those areas that have an impact on his design. The formats provide cost-driver effects (CDE) for qualitative guidance to lowest cost and cost-estimating data (CED) in man-hours for conducting trade studies.

FORMAT SELECTION AID

MECHANICALLY FASTENED ASSEMBLIES

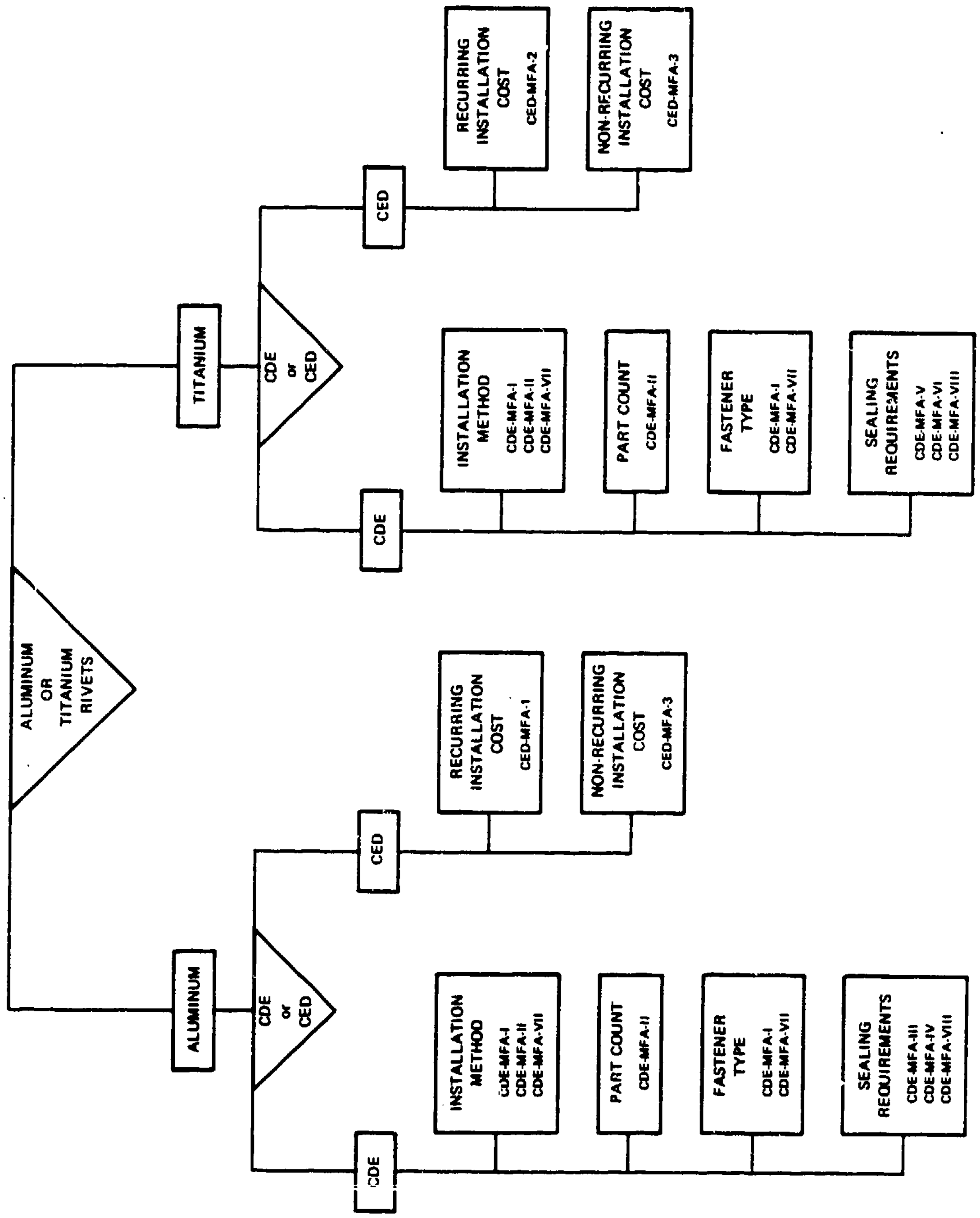


FIGURE 4.2-1

4.2.2 Example of Utilization

This example demonstrates to the designer how the mechanically fastened assembly data is utilized on a specific design problem. The example shows how to identify applicable formats, how to extract data from the formats, and provides a discussion on how the data are used to determine the part cost in man-hours or dollars. The MC/DG cost worksheet can be used to record the cost data for easy reference and to determine the total program cost. The MC/DG worksheet appears as Table 3-3.

4.2.2.1 Utilization Example of Aluminum First Level Assembly

Problem Statement

Determine manufacturing cost (man-hours) for an aluminum (2024) first level assembly shown in Figure 4.2-1. The order will be for 200 units.

Procedure

The following procedure is used to determine the manufacturing cost (man-hours) for the assembly.

1. Review the Format Selection Aid (Fig. 4.2-1) for Mechanically Fastened Assemblies.
2. Determine the formats to use. In this case, Formats CED-MFA-1 (Fig. 4.2-3) and CED-MFA-3 (Fig. 4.2-4) are required.
3. Study the formats to determine the parameters and conditions needed for use. To use CED-MFA-1, the number of fasteners, fastening method, and sealing requirements must be specified. The sketch indicates 133 fasteners with the faying surface sealed. For this example, manual and automatic riveting will be considered. To use CED-MFA-3, the part perimeter (ft) and fastening method is required. The perimeter in this case is 14.4 ft, and again, both automatic and manual riveting will be considered by the designer.
4. Determine the values for recurring cost and nonrecurring tooling cost (NRTC) from the formats:
   - (a) Manual
     - From CED-MFA-1, read that the recurring cost = 5.0 man-hours per part
     - From CED-MFA-3, read that NRTC = 420 man-hours
       NRTC = 420 man-hours per 200 parts
       = 2.10 man-hours per part
     - The learning curve factor to convert unit cost at 200 to cumulative average cost for an 80 percent curve and a quantity of 200 is 1.45 (see (Table 4.2-1).

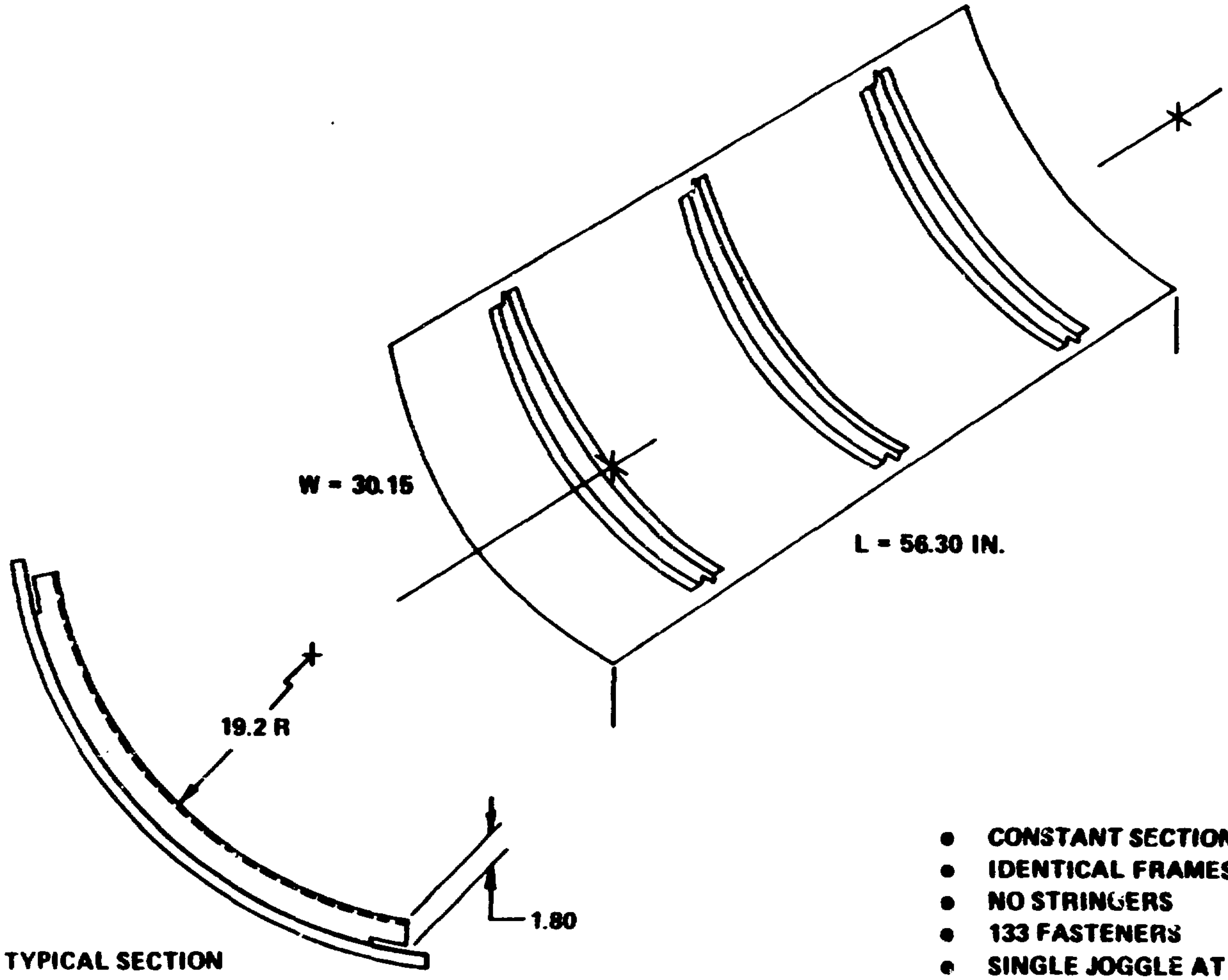
     Total cost = 1.45 (5.0) + 2.1 = 9.35 man-hours per part.

(b) Automatic

- From CED-MFA-1, read that recurring cost at unit 200 = 3.25 man-hours per part
- From CED-MFA-3, read that
  NRTC = 440 man-hours per 200 parts
  = 2.2 man-hours per part.

Total cost = 1.45 (3.25) + 2.2 = 6.91 man-hours per part.

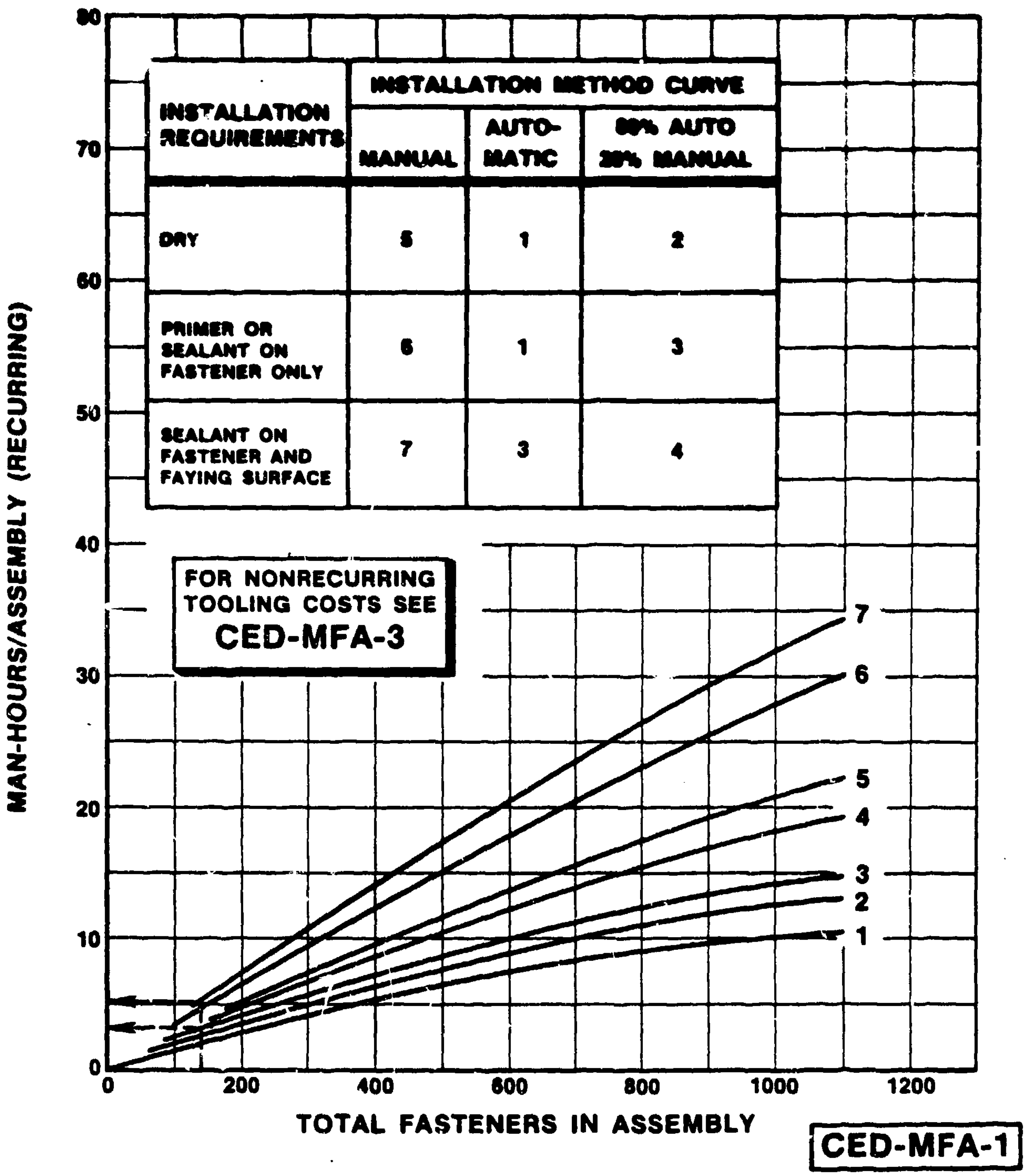
5. No applicable DICE are indicated, and, therefore, the costs determined above are the final total costs for assembling the part.



- CONSTANT SECTION RADIUS
- IDENTICAL FRAMES
- NO STRINGERS
- 133 FASTENERS
- SINGLE JOGGLE AT FRAME ENDS
- SEAL FAYING SURFACES

FIGURE 4.2-2. ALUMINUM (2024) FIRST LEVEL ASSEMBLY STATEMENT

INSTALLATION COSTS FOR ALUMINUM RIVETS



INSTALLATION REQUIREMENTS	INSTALLATION METHOD CURVE		
	MANUAL	AUTO-MATIC	80% AUTO 20% MANUAL
DRY	5	1	2
PRIMER OR SEALANT ON FASTENER ONLY	6	1	3
SEALANT ON FASTENER AND FAYING SURFACE	7	3	4

FIGURE 4.2-3. FORMAT USED IN EXAMPLE

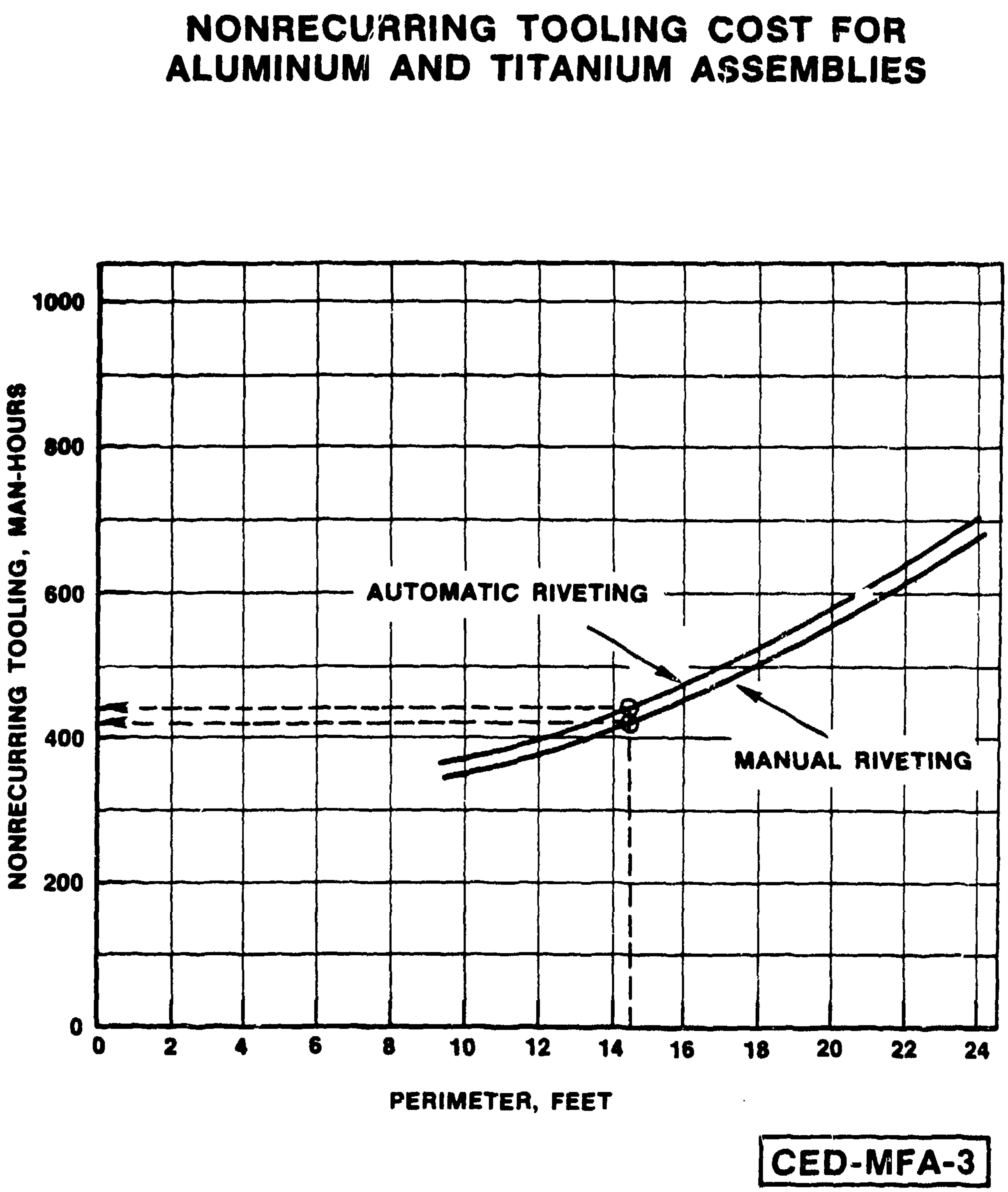


FIGURE 4.2-4. FORMAT USED IN EXAMPLE

TABLE 4.2-1

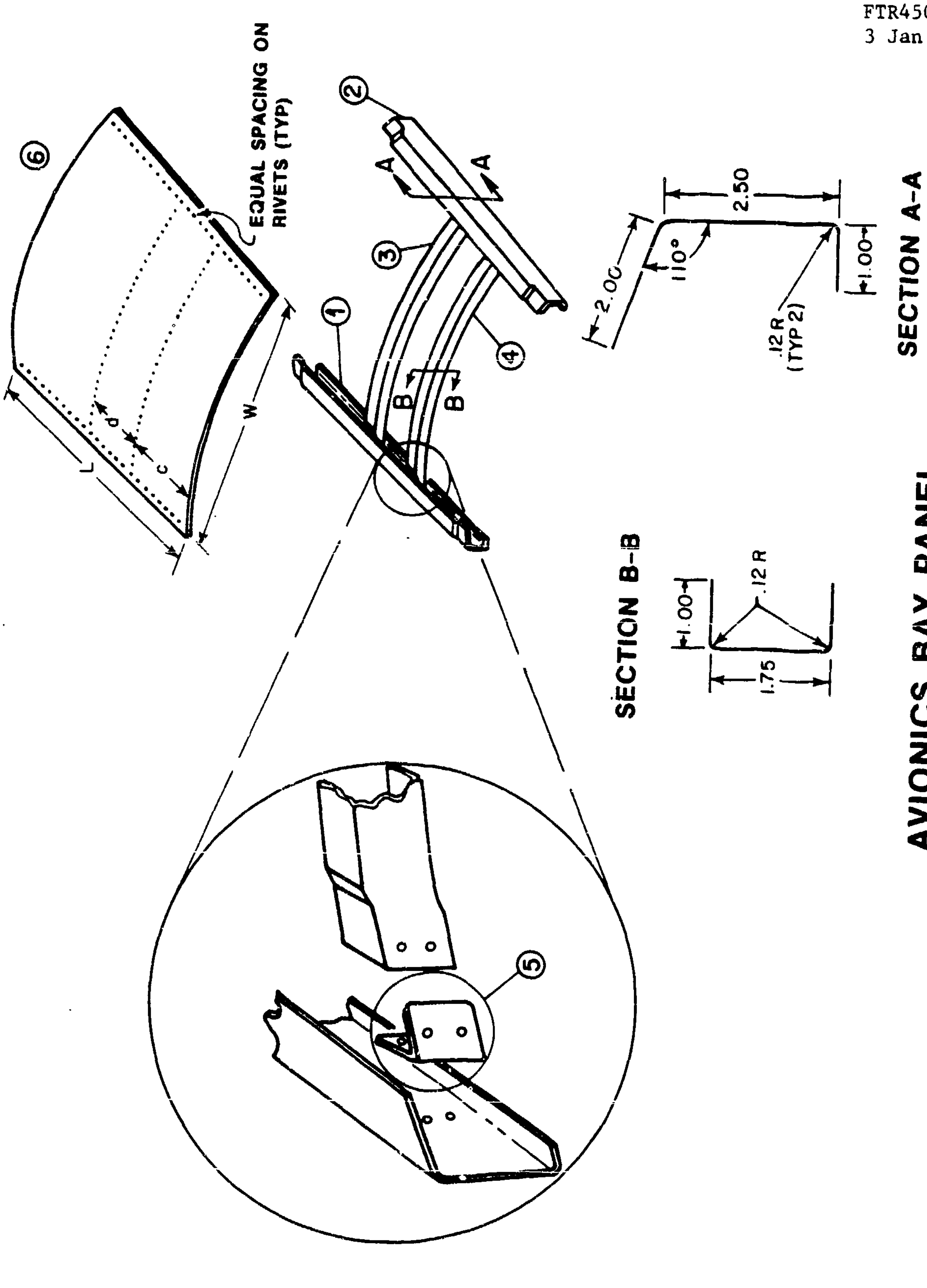
FACTORS TO CONVERT THE MC/DG 200TH UNIT COST TO THE CUMULATIVE AVERAGE COST FOR THE DESIGN QUANTITY AND LEARNING CURVE INVOLVED

DESIGN QUANTITY	LEARNING CURVE-%						
	95	90	85	80	75	70	65
1	1.48	2.25	3.48	5.50	9.00	15.00	27.00
10	1.33	1.79	2.47	3.48	5.04	7.53	11.67
25	1.25	1.59	2.05	2.71	3.68	5.13	7.43
50	1.19	1.44	1.79	2.22	2.85	3.76	5.14
100	1.13	1.30	1.52	1.80	2.18	2.73	3.51
200	1.08	1.17	1.30	1.45	1.66	1.95	2.36
350	1.04	1.08	1.14	1.22	1.33	1.48	1.70
500	1.01	1.02	1.05	1.09	1.15	1.24	1.38
750	0.98	0.96	0.96	0.96	0.97	1.01	1.09
1000	0.96	0.92	0.89	0.87	0.87	0.88	0.91

4.2.3 Airframe Assemblies

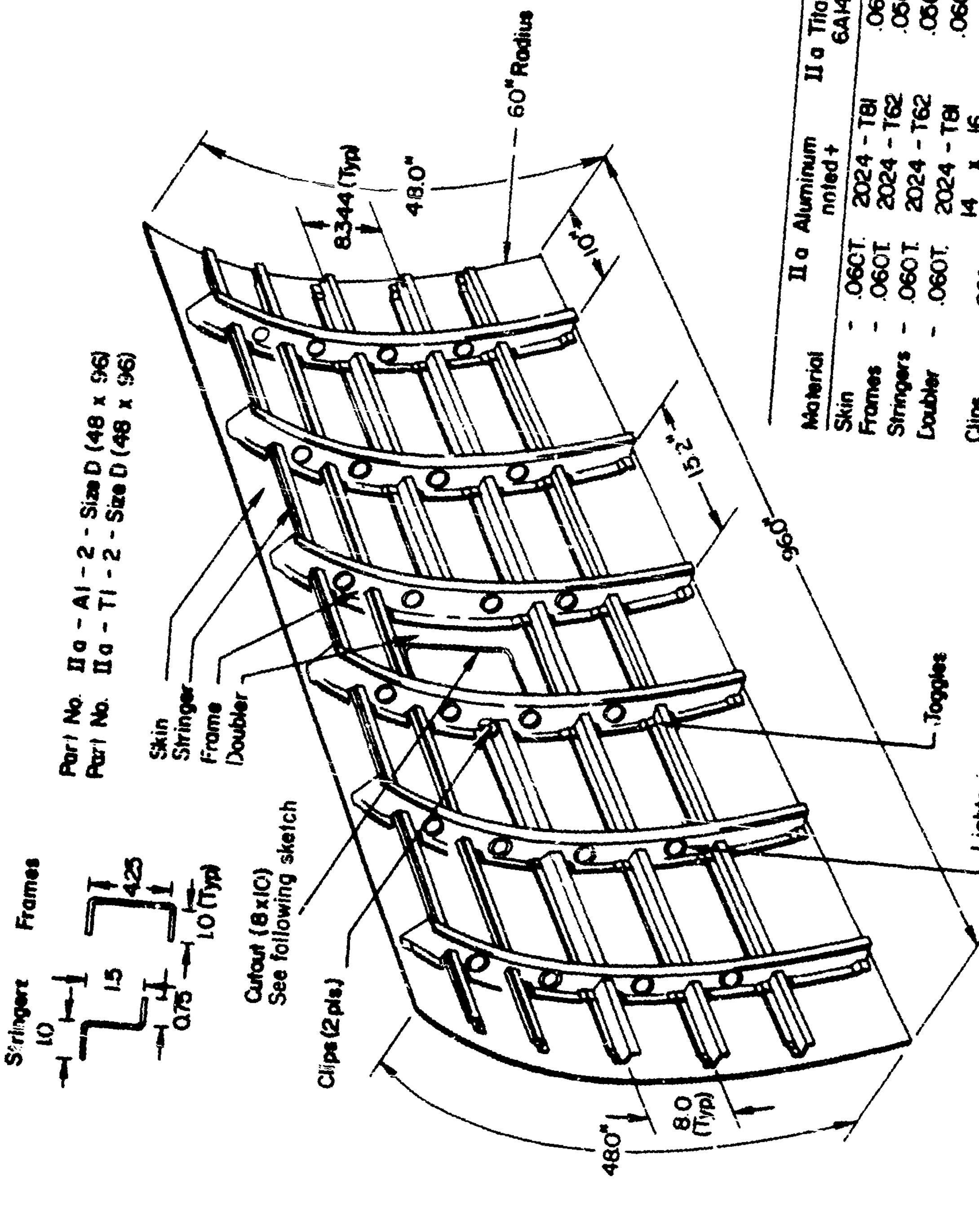
To determine the manufacturing man-hours for first-level mechanically fastened assemblies, the assemblies shown in Figures 4.2-5 to 4.2-8 were analyzed. The assemblies were:

- Avionics Panel
- Fuselage Panel
- Fuselage Door.



AVIONICS BAY PANEL

FIGURE 4.2-5. ASSEMBLY ANALYZED TO DEVELOP DATA



Material		IIa Aluminum noted+	IIa Titanium 6Al4V
Skin	-	.060T. 2024-T81	.060
Frames	-	.060T. 2024-T62	.050
Stringers	-	.060T. 2024-T62	.050
Doubler	-	.060T. 2024-T81	.060
Clips	-	.060 14 x 16 2024-T62	

MECHANICALLY FASTENED ASSEMBLY FUSELAGE PANEL

FIGURE 4.2-6. ASSEMBLY ANALYZED TO DEVELOP DATA

FUSELAGE CUT-OUT

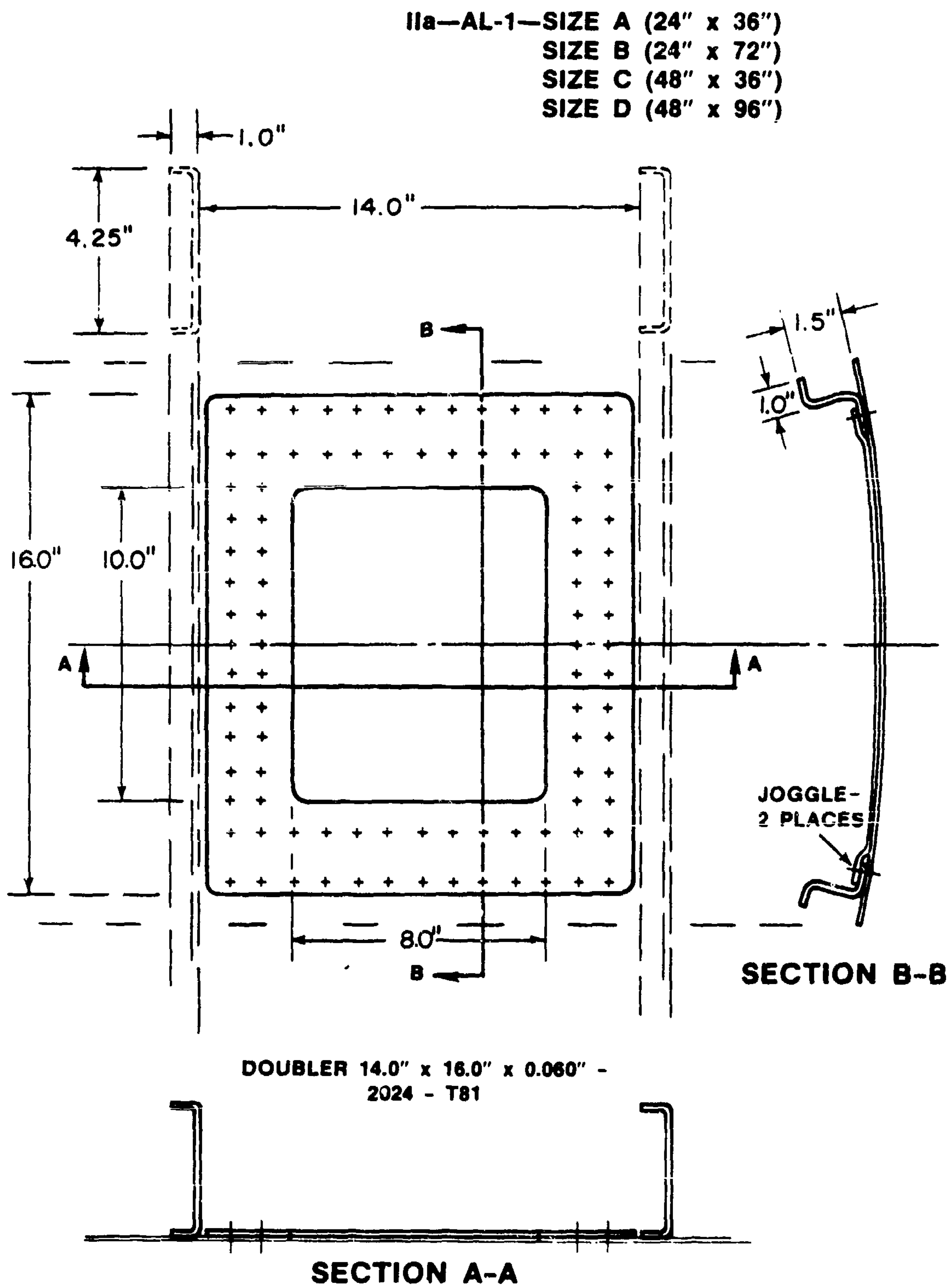


FIGURE 4.2-7. DETAILS OF WINDOW IN FIGURE 4.2-5

FUSELAGE DOOR ASSEMBLY

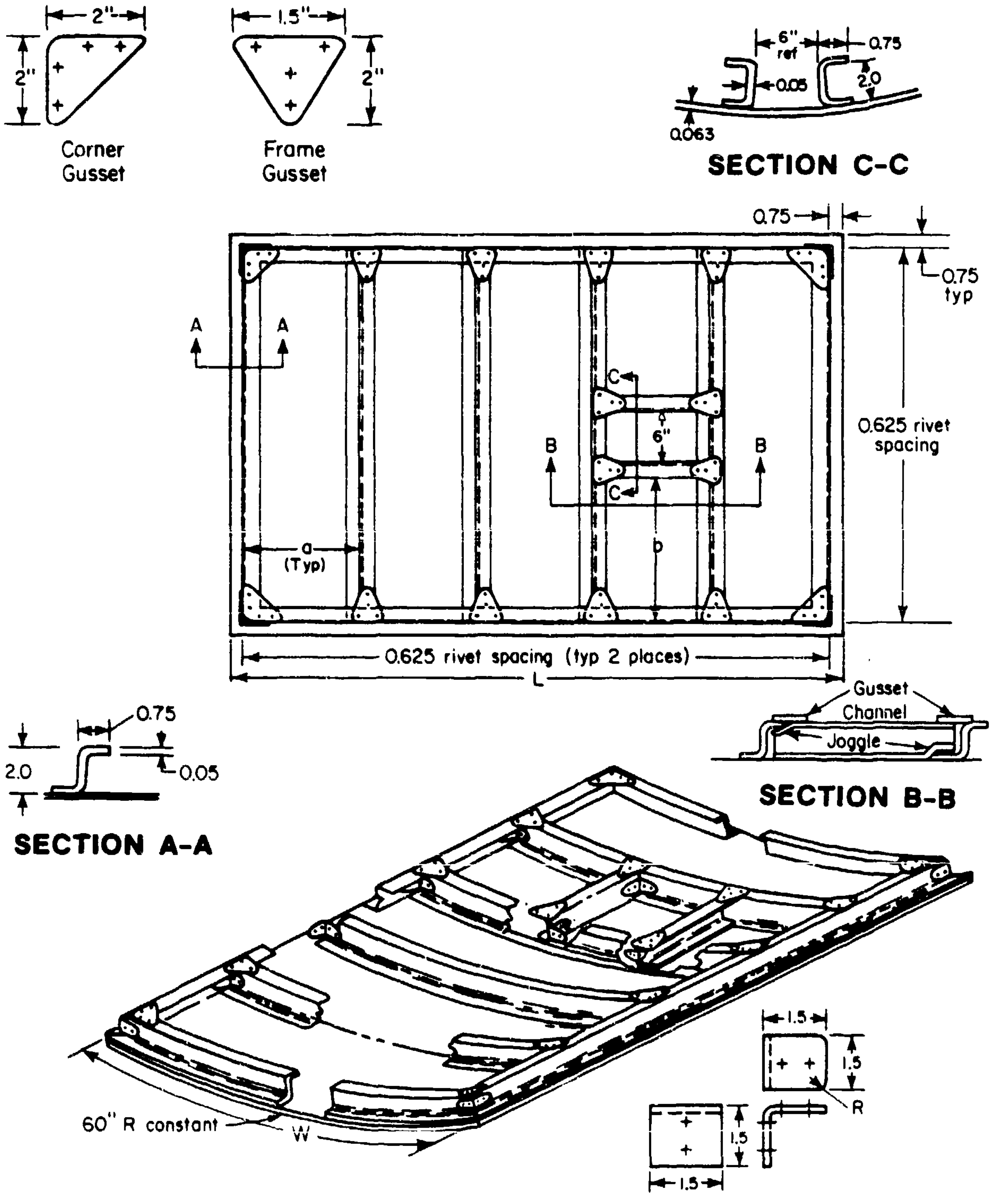


FIGURE 4.2-8 ASSEMBLY ANALYZED TO DEVELOP DATA

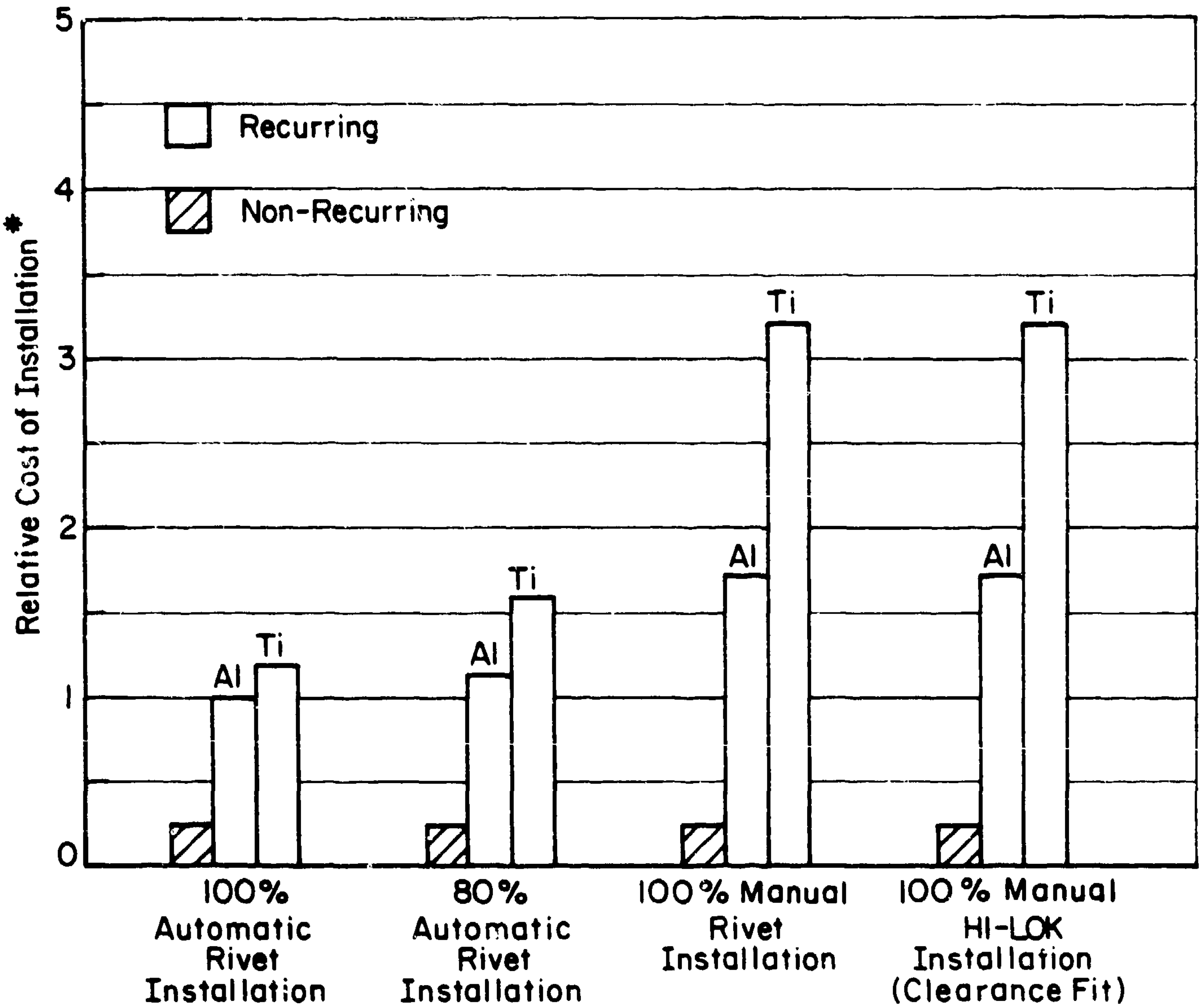
TABLE 4.2-2. DIMENSIONS AND MATERIALS OF ASSEMBLIES ANALYZED

Assembly Type	Material	Size Classification	Size, Inches
Avionics Bay Panel	Aluminum-1	A	24x36
		B	24x72
		C	48x36
		D	48x96
Fuselage Panel	Aluminum-2	A	24x36
		B	24x72
		C	48x36
		D	48x96
Fuselage Door	Aluminum-3	A	24x36
		B	24x72
		C	48x36
		D	48x96
Avionics Bay Panel	Titanium-1	A	24x36
		B	24x72
		C	48x36
		D	48x96
Fuselage Panel	Titanium-2	A	24x36
		B	24x72
		C	48x36
		D	48x96
Fuselage Door	Titanium-3	A	24x36
		B	24x72
		C	48x36
		D	48x96

4.2.4 Manufacturing Data for Airframe Assemblies

The following data for airframe assemblies are presented using cost-estimating data (CED) and cost-driver effect (CDE) formats for conducting trade-studies.

EFFECT OF INSTALLATION METHOD FOR ALUMINUM AND TITANIUM ASSEMBLIES

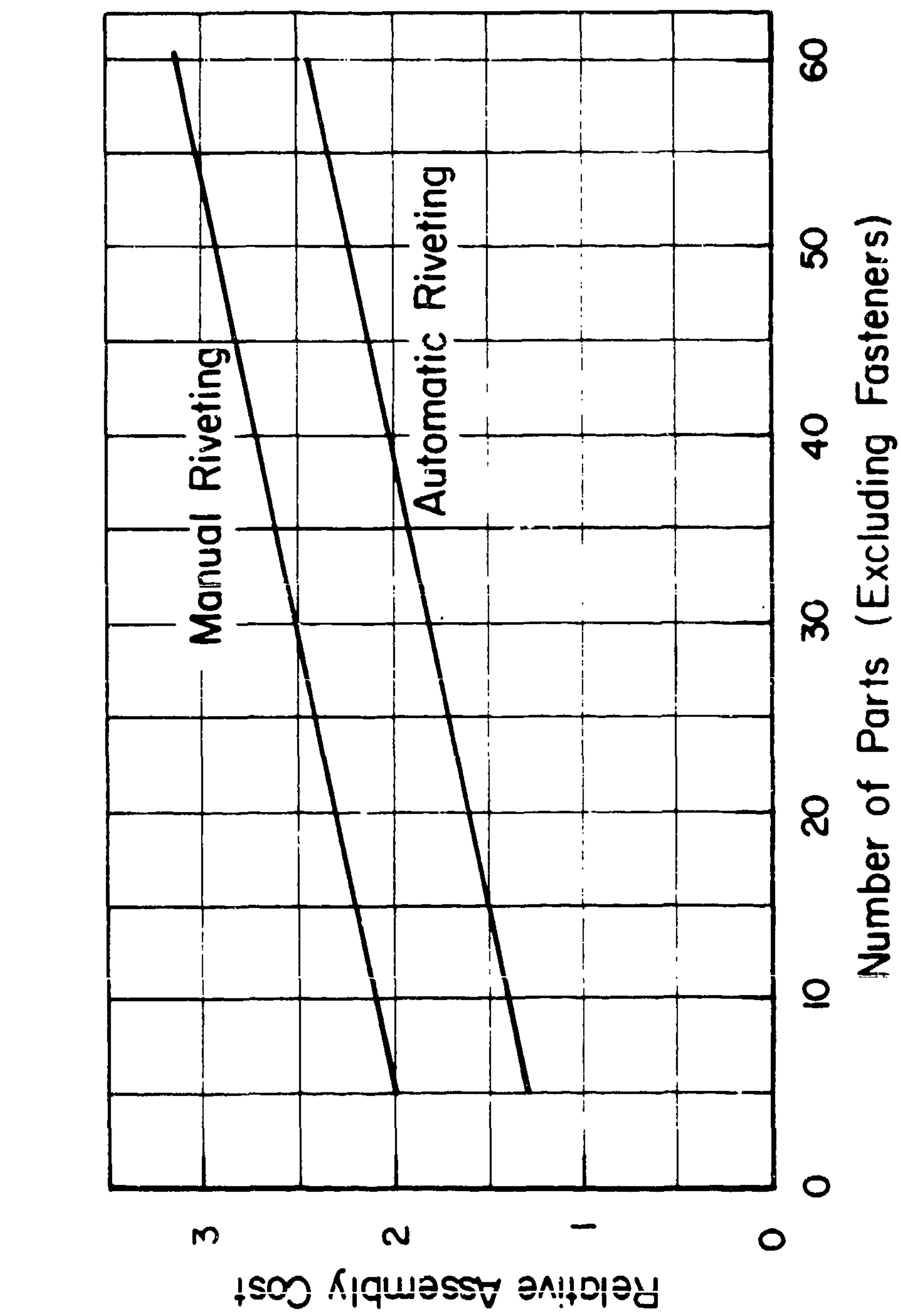


* Includes the complete operation-hole preparation and fastener setting

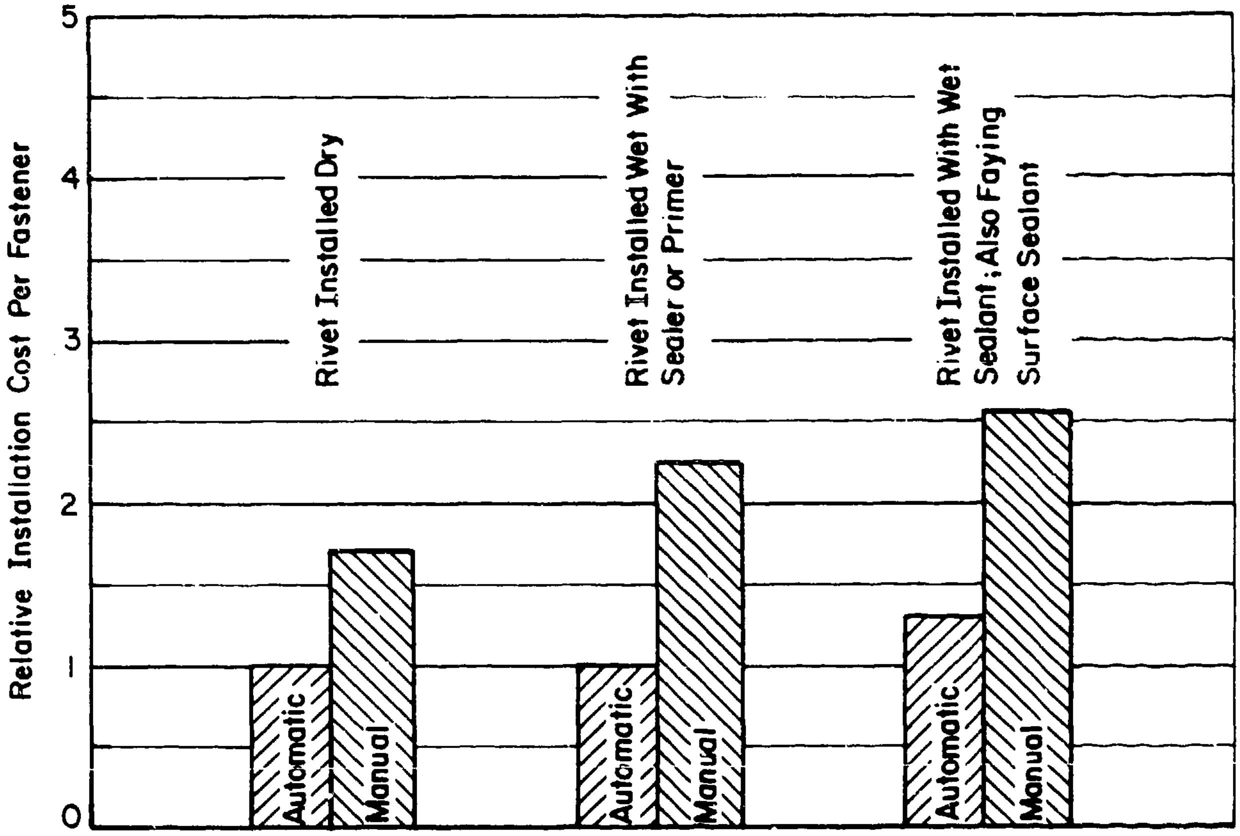
CDE-MFA-I

CDE-MFA-II

EFFECT OF PART COUNT AND FASTENING METHOD

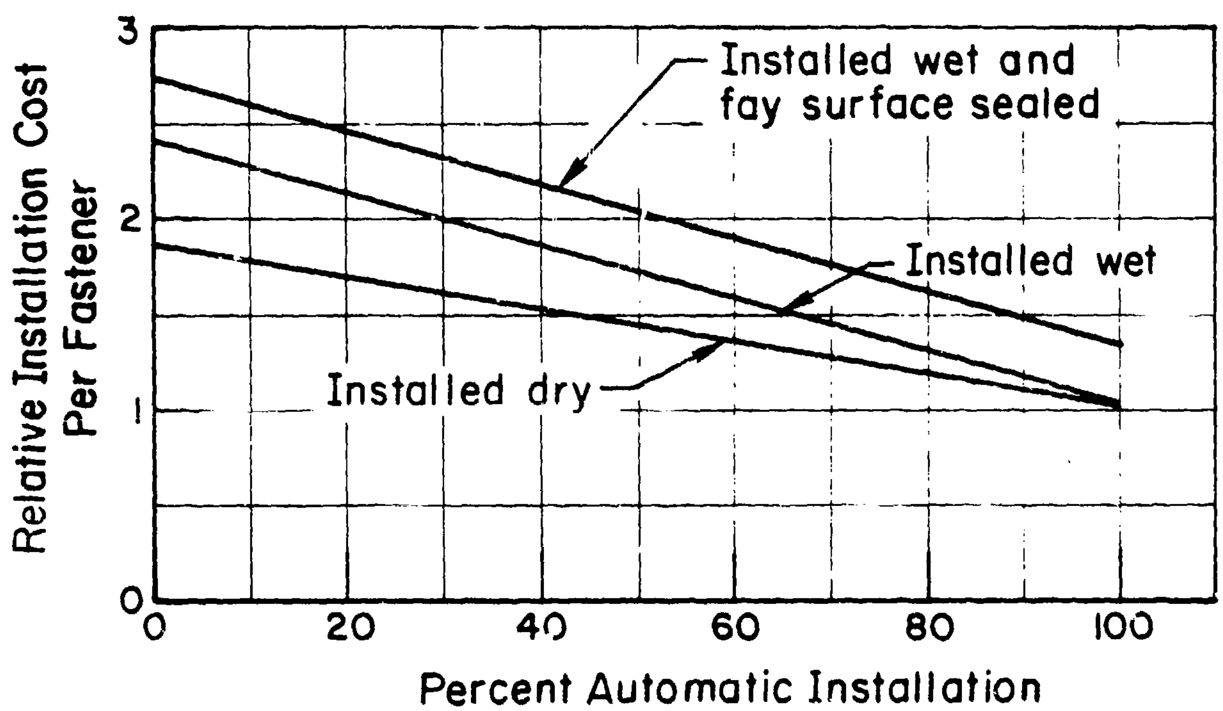


EFFECTS OF SEALING ON FASTENER INSTALLATION COST
ALUMINUM ASSEMBLIES



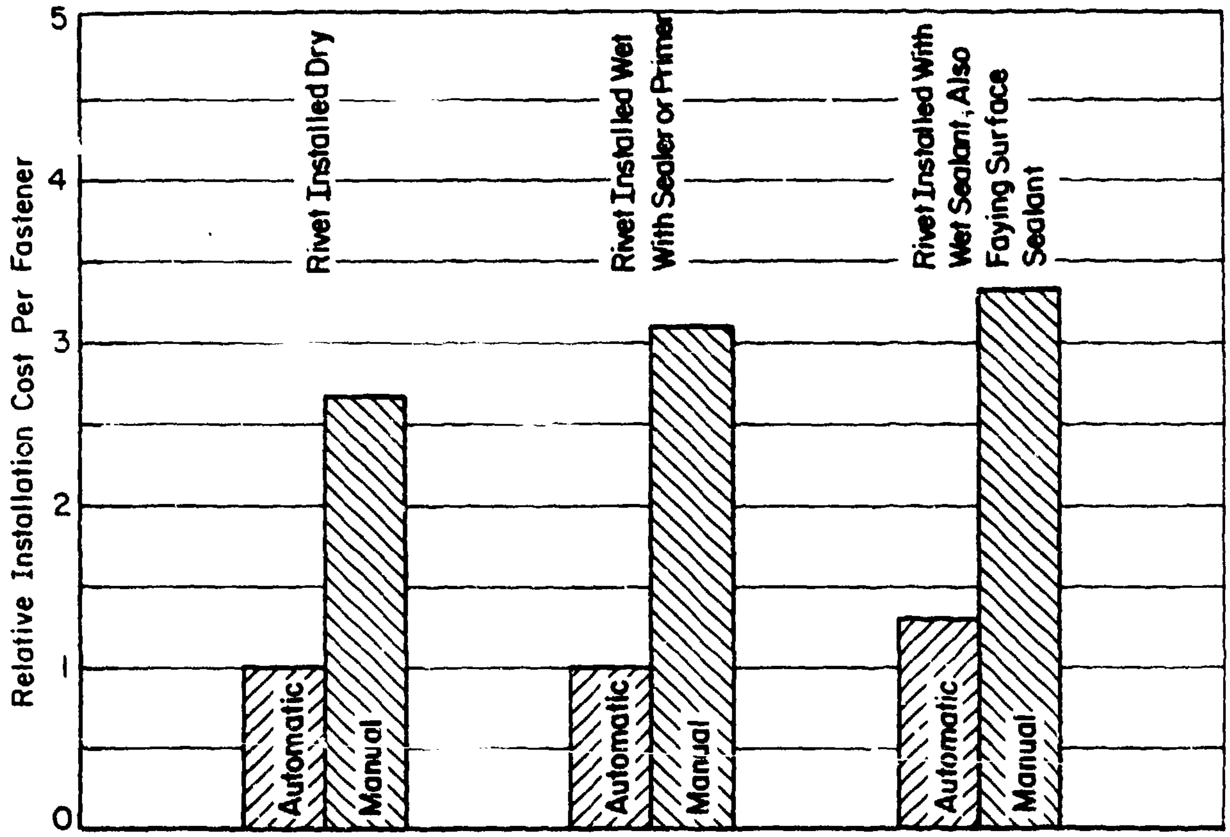
CDE-MFA-III

EFFECT OF SEALING ON ASSEMBLY COST
ALUMINUM ASSEMBLIES



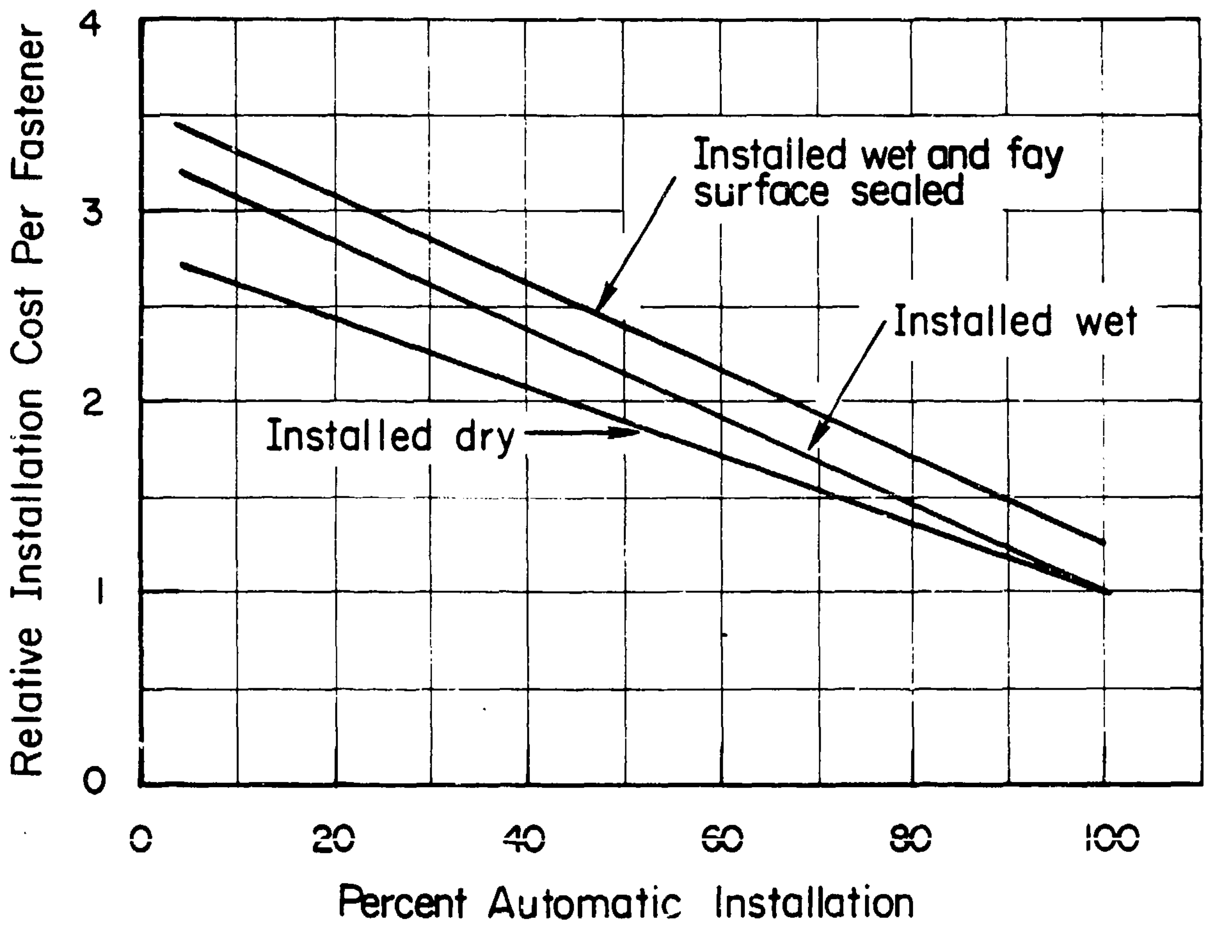
CDE-MFA-IV

EFFECTS OF SEALING ON FASTENER INSTALLATION COST
TITANIUM ASSEMBLIES



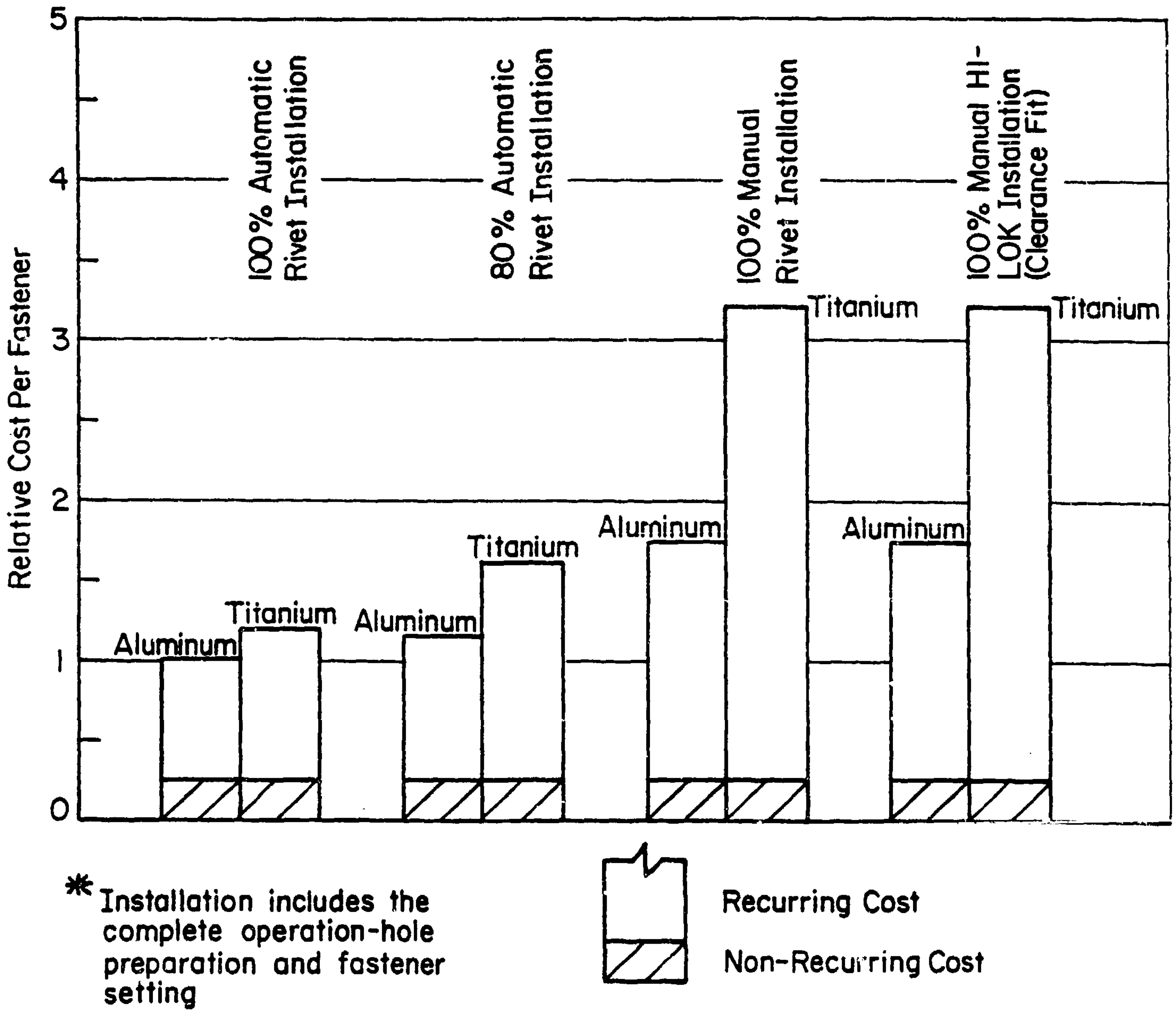
CDE-MFA-V

EFFECT OF SEALING ON ASSEMBLY COST
TITANIUM ASSEMBLIES



CDE-MFA-VI

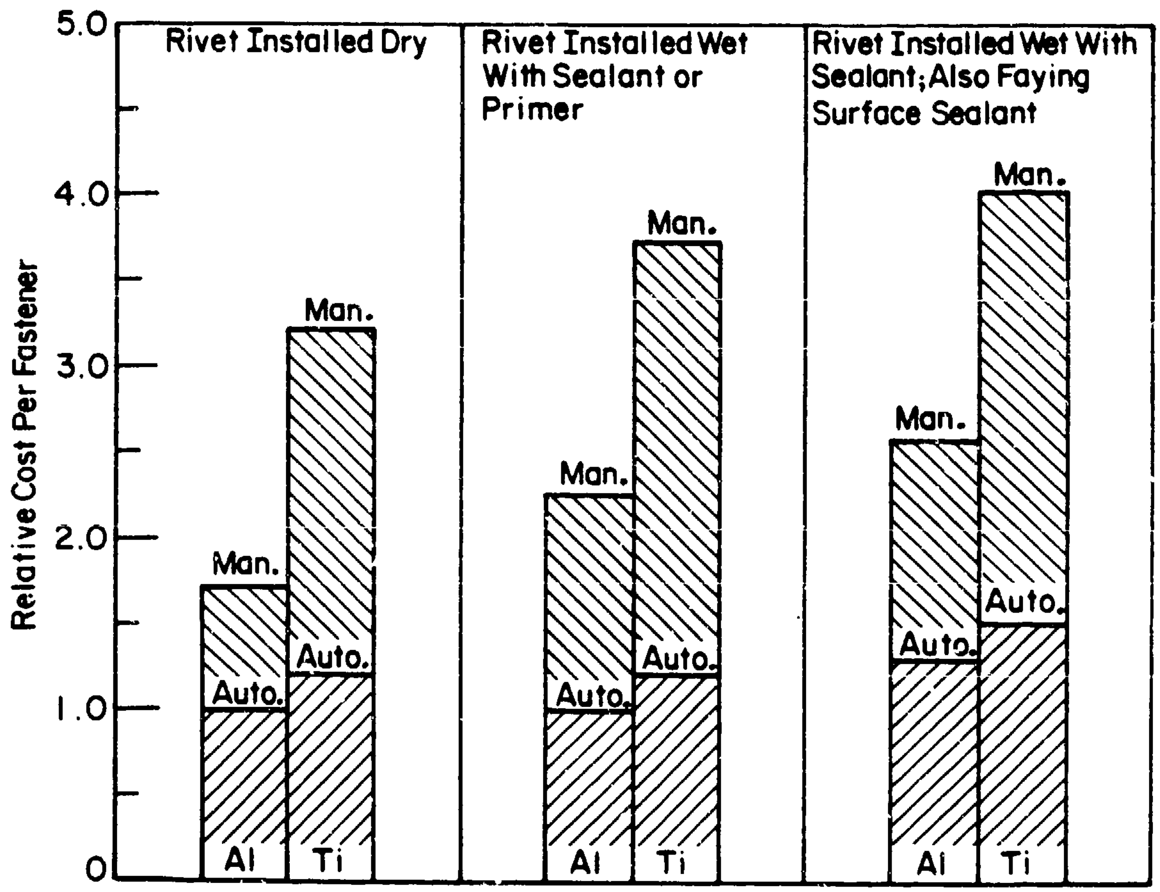
COST EFFECTS OF INSTALLATION* METHOD, ASSEMBLY MATERIAL AND FASTENER TYPE



*Installation includes the complete operation-hole preparation and fastener setting

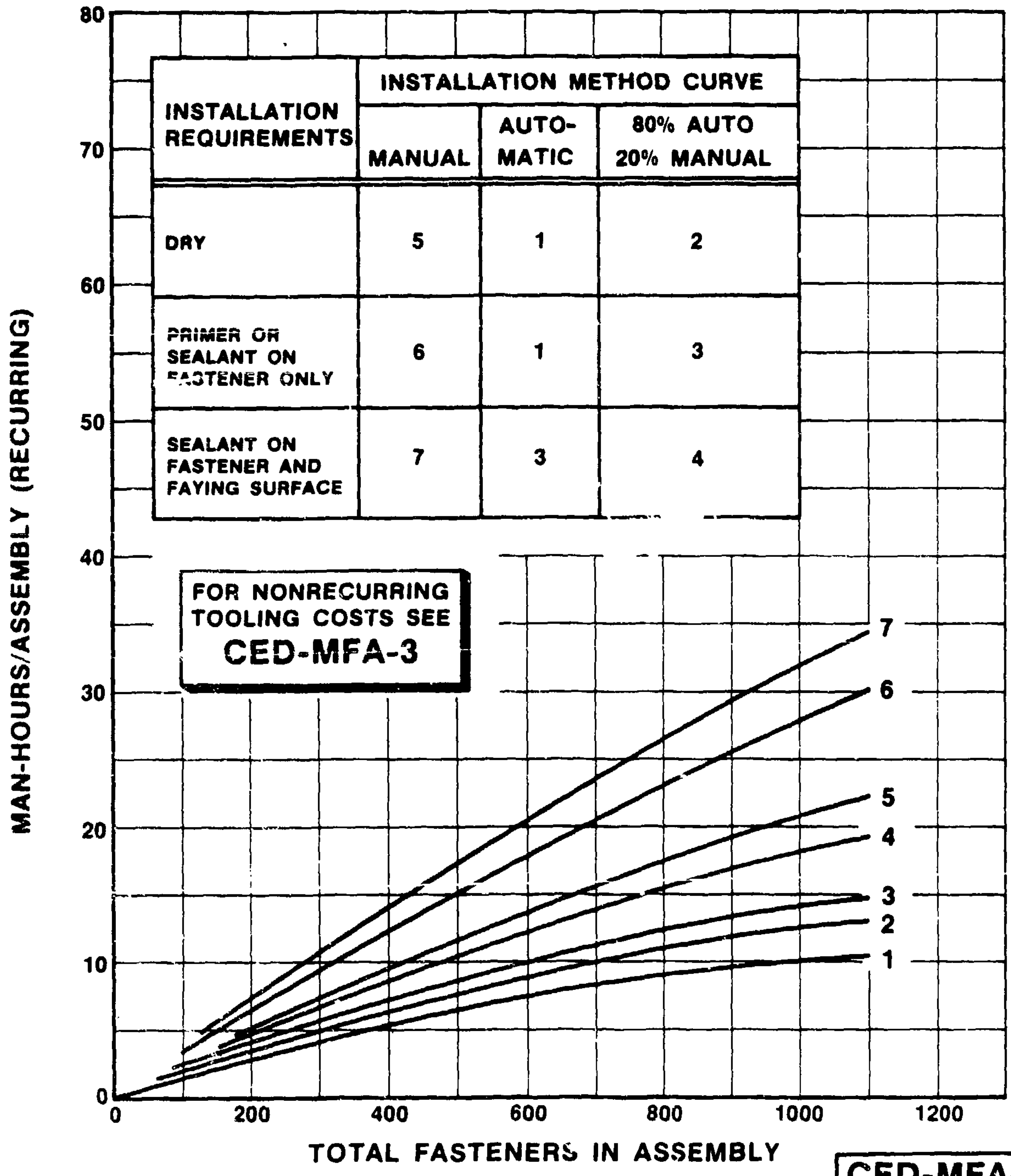
CDE-MFA-VII

EFFECT OF SEALING ON FASTENER INSTALLATION COST: ALUMINUM AND TITANIUM ASSEMBLIES



CDE-MFA-VIII

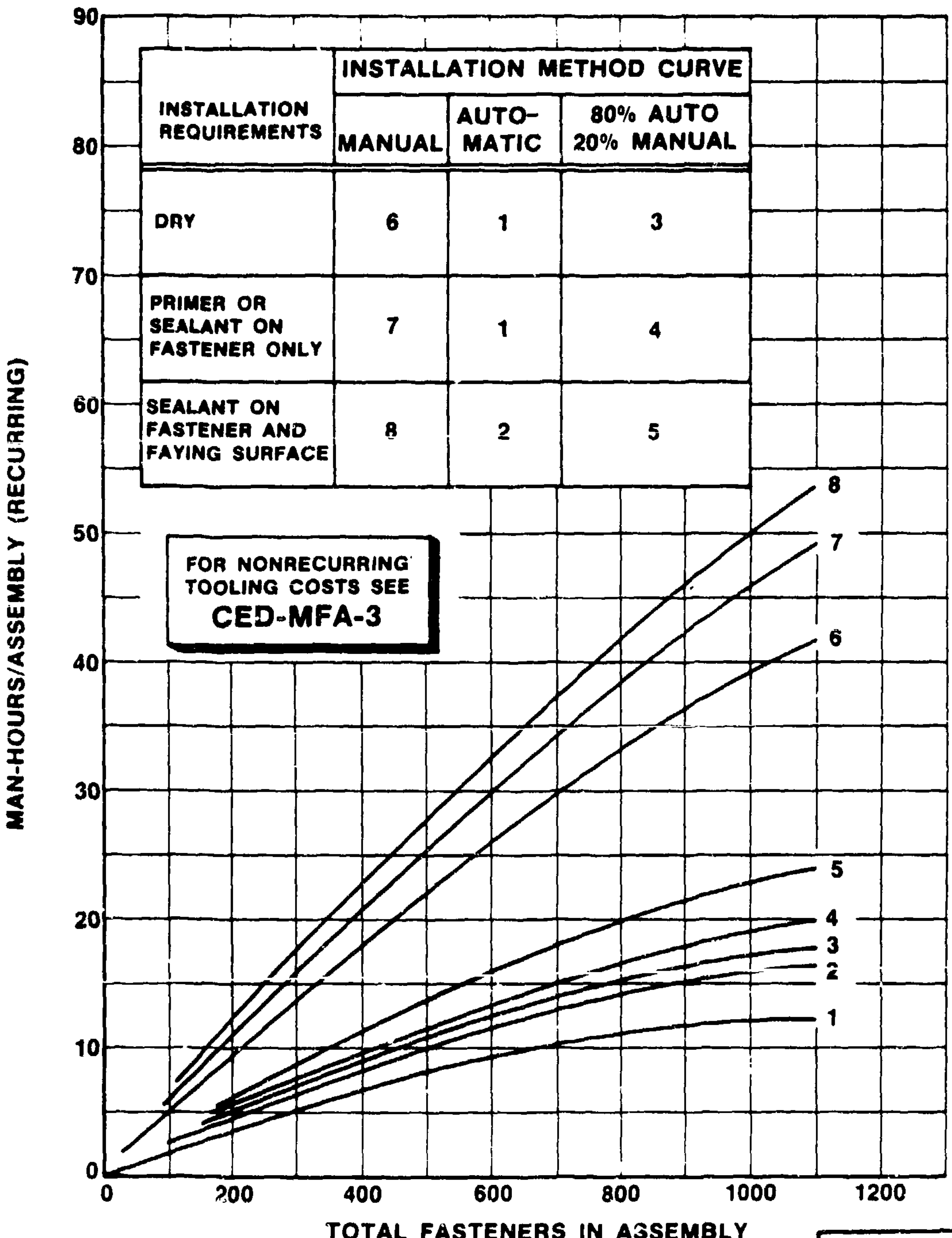
INSTALLATION COSTS FOR ALUMINUM RIVETS



INSTALLATION REQUIREMENTS	INSTALLATION METHOD CURVE		
	MANUAL	AUTO-MATIC	80% AUTO 20% MANUAL
DRY	5	1	2
PRIMER OR SEALANT ON FASTENER ONLY	6	1	3
SEALANT ON FASTENER AND FAYING SURFACE	7	3	4

CED-MFA-1

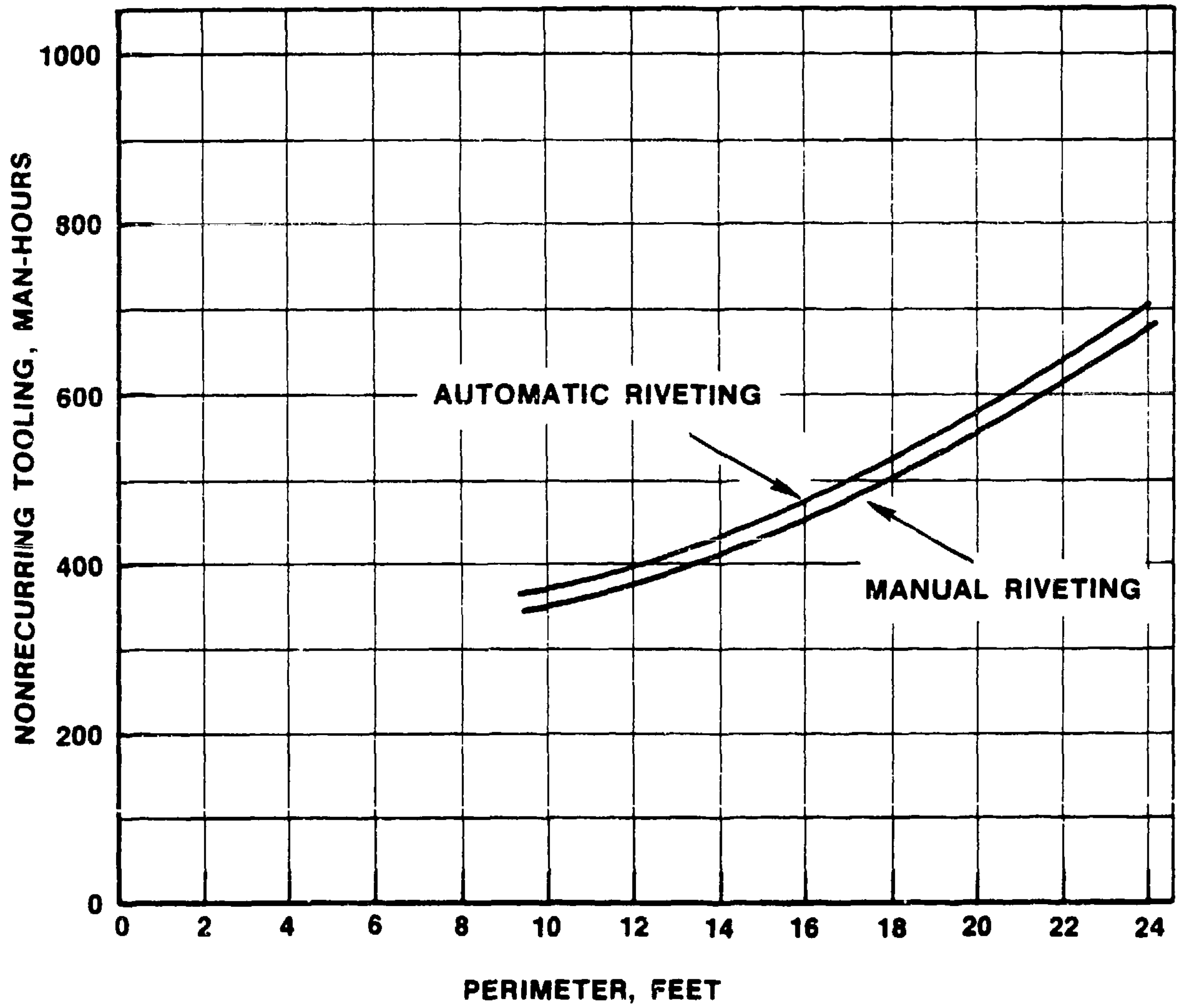
INSTALLATION COSTS FOR TITANIUM RIVETS



INSTALLATION REQUIREMENTS	INSTALLATION METHOD CURVE		
	MANUAL	AUTO-MATIC	80% AUTO 20% MANUAL
DRY	6	1	3
PRIMER OR SEALANT ON FASTENER ONLY	7	1	4
SEALANT ON FASTENER AND FAYING SURFACE	8	2	5

CED-MFA-2

NONRECURRING TOOLING COST FOR ALUMINUM AND TITANIUM ASSEMBLIES



CED-MFA-3

4.2.5 Ground Rules for Mechanically Fastened Assembly Section

The following General and Detailed Ground Rules for the Mechanically Fastened Assembly Section were developed to establish the scope of the data required and to establish guidance to MC/DG application. Ground rules are necessary and important as they promote understanding, ensure consistency, uniformity, and accuracy in generating and integrating data into the formats.

4.2.5.1 General Ground Rules

The general ground rules are categorized under the following major groupings:

(a) First-Level Mechanically Fastened Assemblies (MFA)
(b) Materials
(c) Assembly Methods
(d) Facilities
(e) Data Generation - Recurring Costs
(f) Data Generation - Nonrecurring Costs
(g) Test and Evaluation of Data
(h) Support Function Modifiers.

(a) First-Level Mechanically Fastened Assemblies (MFA)

(1) The MFA were selected to provide, where possible, data for more than one manufacturing assembly method to enable the designer to select the most cost-competitive method in trade studies by making cost comparisons.

(2) The assemblies selected are representative of common first-level structural assemblies required in both small and large aircraft. The majority of discrete parts utilized in these assemblies was selected from the Demonstration Section for "Sheet Metal Aerospace Discrete Parts", to form the foundation so that the designer can modify the part, as required, to achieve

the desired structural foundation and configuration. The assemblies selected were an avionics bay panel, a fuselage panel with a cutout, and a fuselage door assembly.

(3) Drawings were developed defining the selected assemblies in the required detail to conduct the cost estimating analysis.

(b) Materials

(1) The materials selected for the assemblies are:

- Aluminum - 2024
- Titanium - 6A1-4V.

(2) Raw materials and fastener costs are not included in the MC/DG formats for MFA but were addressed in the Fuselage Shear-Panel Trade Studies.

(3) The material cost for the tooling was not included.

(c) Assembly Methods

(1) Only conventional methods of assembly were evaluated to assemble the parts.

(2) A production environment was assumed for the selected assemblies.

(3) To generate an effective manufacturing man-hour data base for each selected assembly, the operational sequence for the applicable manufacturing technologies was established reflecting the most economical procedure. The operational sequence was standardized then used by each team member, as the standard, to determine the base assembly cost. The operational sequences are indicated in Appendix E.

(4) Nonrecurring tooling costs (NRTC) for the manufacture of the various assemblies were provided on the Data Collection Forms.

(d) Facilities

(1) Only conventional or standard manufacturing facilities available in the airframe industry were considered.

(e) Data Generation - Recurring Costs

(1) Recurring man-hour data were generated for the complete assembly process to include all hands-on-factory direct labor operations from initial preparation for jig loading, drilling, and fastener installation, to storage for the next assembly phase.

(2) A base cost was generated for each assembly type. This base part was configuration IIa-1-size A (24 in x 36 in) avionics panel assembly with 100 percent automatic installation of fasteners common to skin and sub-structure.

(3) Designer-influenced cost elements (DICE) were treated as separate cost elements over and above the base assembly cost.

(4) The quantity for which the base assembly cost was determined was unit 200.

(5) Man-hours associated with DICE and other cost drivers were identified.

(6) The data were represented in man-hours.

(7) Assembly time consists of the direct man-hours to set up and complete the assembly operation.

(8) Recurring tooling costs (tool maintenance, planning, etc.) were not included.

(9) In developing cost data for assemblies, the participating companies used common, but proprietary, learning curves.

(10) The assembly man-hours, as derived by each airframe company, were normalized by BCL to reflect an industry team average value for each assembly.

(11) For proprietary reasons, realization factors, including personal fatigue and delay (PF&D), individual company standards, and other business-sensitive information employed at team member companies were not included in the analysis or on the data sheets or MC/DG formats.

(f) Data Generation - Nonrecurring Costs

(1) Tool fabrication man-hours were developed for each assembly type. Tool design and tool planning man-hours were not included.

(2) The cost of production assembly tooling was restricted to contract or project tools only.

(3) Nonrecurring tooling costs (NRTC) generated by the team companies were normalized by BCL for presentation in the MC/DG formats for MFA.

(g) Test and Evaluation of Data

(1) Test and confirmation of the formats and integrated data were accomplished by two team members. Each of the remaining three team members was provided with the data inserted on the MC/DG formats. In order to gain confidence and ensure the validity of the formatted data, the selected configurations were submitted to cost-estimators in other team companies. These data were then compared to the formatted data generated and evaluated to assess its credibility. Any anomalies were resolved and modifications incorporated, if appropriate.

(h) Support Function Modifiers

(1) Additional efforts other than factory labor, such as quality control and assurance, manufacturing engineering, and planning, were excluded from the assembly man-hour data supplied to BCL. These modifiers may be included later by MC/DG airframe company users.

4.2.5.2 Detailed Ground Rules

(1) Manufacturing assembly methods evaluated:
- Manual installation--impact of squeeze
- Automatic installation--manual positioning.

(2) Fastener types evaluated:
- Upset rivets
  - Aluminum panel--AD rivets
  - Titanium panels--bitmetallic titanium rivets
- Pins
  - Titanium
- Collar
  - Aluminum panel--aluminum collar
  - Titanium panel--Cres collar.

(3) Flush fasteners were countersunk:
- No dimpling (skin gages selected were sufficiently thick to make dimpling unnecessary).

(4) Hole preparation accomplished by combination of drill and countersink.

(5) Tolerances--location and hole sizes corresponded to individual company standards.

(6) No shimming, fitup, or trimming of assembly.

(7) Rivet heads were as driven with no shaving required.

(8) No sealing required in baseline assemblies.

(9) No mastered hard points or interchangeability requirements.

(10) Manual assemblies were assumed to be deburred at mating surfaces.

(11) No finishing, e.g., paint or prime, required after driving fasteners.

(12) All assemblies were evaluated in aluminum and titanium materials.

4.3 Advanced Composite Fabrication Section

This section contains format selection aids, identification of the types of parts analyzed for data to determine the manufacturing man-hour data, examples of how the data are utilized in airframe design and a set of composite MC/DG formats. These formats include cost-driver effects (CDE), cost-estimating data (CED), and designer-influenced cost elements (DICE).

4.3.1 Format Selection Aids

Format selection aids are presented to provide the user with a building-block approach to determine manufacturing cost data for alternative designs or processes. The designer can review the format selection trees and identify those areas that have an impact on his design. The formats provide cost-driver effects (CDE) for qualitative guidance to lowest cost and cost-estimating data (CED) in man-hours for conducting trade-studies.

The CDE formats for designer guidance show the cost effect of material form, tape width, radius of curvature, and also number of plies and bends, and developed width for three different, but typical, structural sections.

The CED formats used for cost trade-studies are included for lineal shapes, panels, and also assembly. The designer-influenced cost elements (DICE) formats shown on the Advanced Composite Fabrication Selection Aid, include strip plies, cutouts, and doublers.

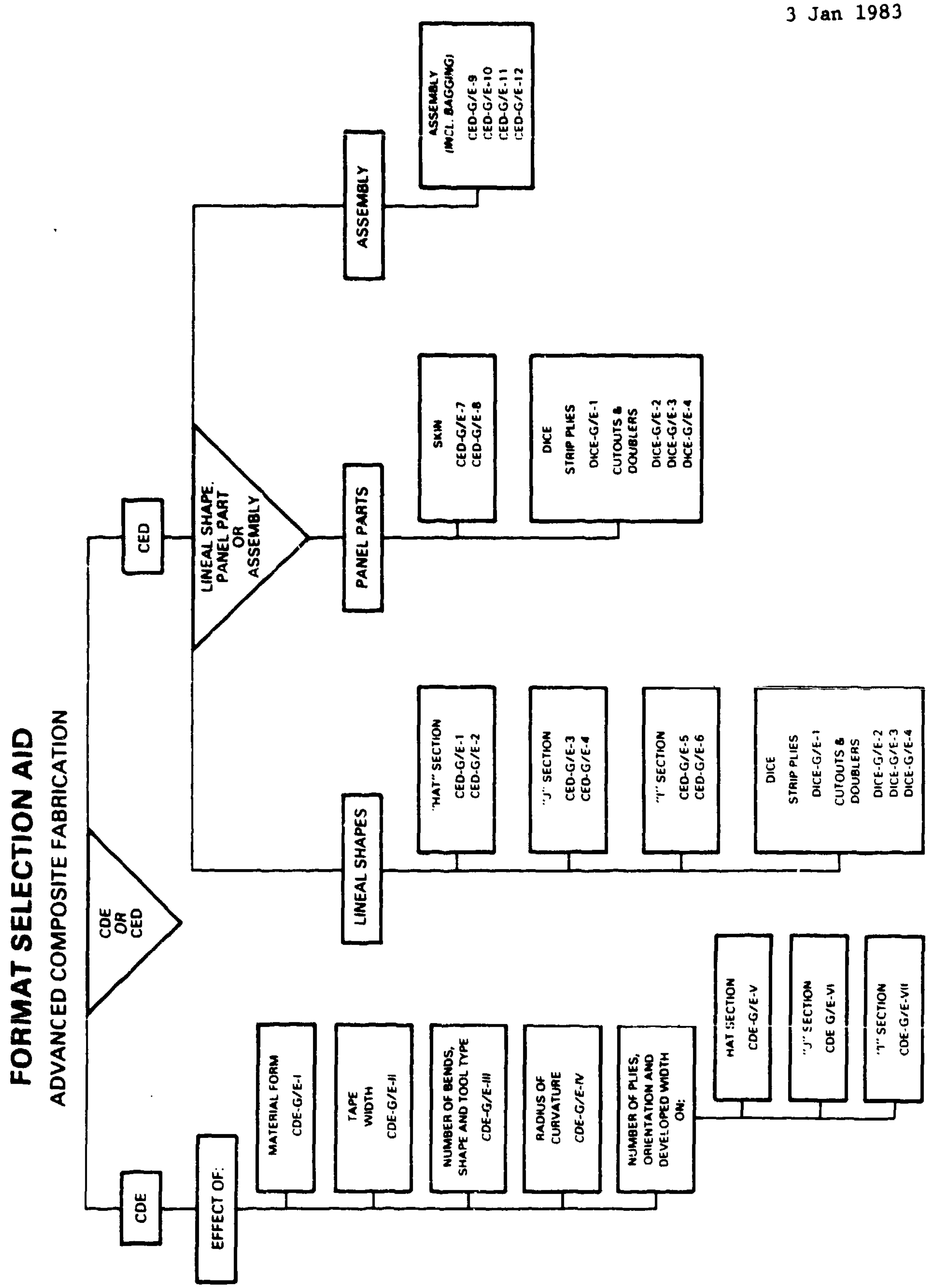

FORMAT SELECTION AID
ADVANCED COMPOSITE FABRICATION
CDE OR CED
CDE
CED
EFFECT OF:
MATERIAL FORM CDE-G/E-I
TAPE WIDTH CDE-G/E-II
NUMBER OF BENDS, SHAPE AND TOOL TYPE CDE-G/E-III
RADIUS OF CURVATURE CDE-G/E-IV
NUMBER OF PLIES, ORIENTATION AND DEVELOPED WIDTH ON:
HAT SECTION CDE-G/E-V
"J" SECTION CDE-G/E-VI
"I" SECTION CDE-G/E-VII
LINEAL SHAPE, PANEL PART OR ASSEMBLY
LINEAL SHAPES
"HAT" SECTION CED-G/E-1 CED-G/E-2
"J" SECTION CED-G/E-3 CED-G/E-4
"I" SECTION CED-G/E-5 CED-G/E-6
DICE STRIP PLIES DICE-G/E-1 CUTOUTS & DOUBLERS DICE-G/E-2 DICE-G/E-3 DICE-G/E-4
PANEL PARTS
SKIN CED-G/E-7 CED-G/E-8
DICE STRIP PLIES DICE-G/E-1 CUTOUTS & DOUBLERS DICE-G/E-2 DICE-G/E-3 DICE-G/E-4
ASSEMBLY
ASSEMBLY (INCL. BAGGING) CED-G/E-9 CED-G/E-10 CED-G/E-11 CED-G/E-12

FIGURE 4.3-1.

4.3.2 Example of Utilization

This example demonstrates how the data generated are utilized on a specific design problem. The example shows how to identify applicable formats, how to extract data from the formats, and provides a discussion on how the data are used to determine the part cost in man-hours or dollars.

4.3.2.1 Utilization Example for Graphite/Epoxy "I" Section

Problem Statement

Determine manufacturing cost (man-hours) for the composite "I" section shown below, in "B" stage condition. This represents a typical stiffener or longeron. The nonrecurring tooling costs are to be amortized for 200 parts.

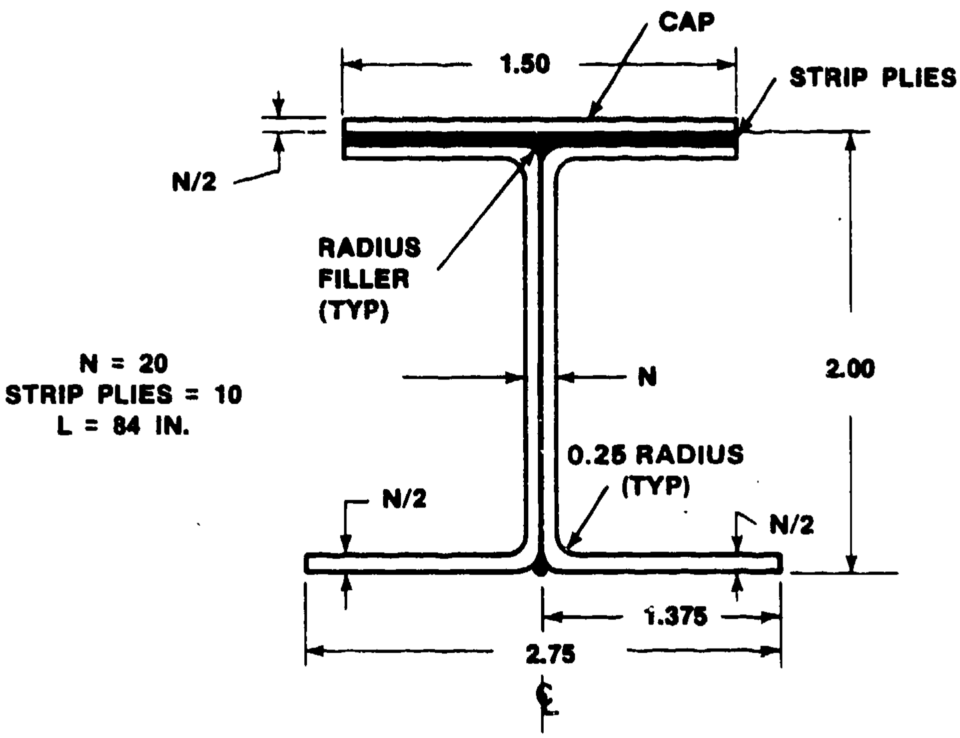


FIGURE 4.3-2. COMPOSITE PART STUDIED

Procedure

The following procedure is used to determine the manufacturing cost (man-hours) for the graphite/epoxy "I" section.

1. Utilize the Format Selection Aid (Figure 4.3-1) for Advanced Composites.
2. Determine which formats are required. In thise case, CED-G/E-5 (Figure 4.3-3) and CED-G/E-6 (Figure 4.3-4) are used.

3. Study the formats to determine parameters and conditions required for use. Format CED-G/E-5 requires part length (ft), number of plies, developed width of the flat pattern (in.), and cure stage. Format CED-G/E-6 requires part length (ft) and developed width (in.). For this example, part length is 7 ft, number of plies is 20, developed width is 9.75 in., and the part is in "B" stage cure.

4. Using CED-G/E-5 and CED-G/E-6, determine the recurring cost and nonrecurring tooling cost (NRTC) for the part.

   - Recurring cost at unit 200 = 11.5 x 0.84 = 9.66 man-hours per part
   - NRTC = 360 man-hours for 200 parts, or 1.80 man-hours per part
   - The learning curve factor to convert unit cost of 200 to cumulative average cost for an 85 percent learning curve and a quantity of 200 is 1.30 (Table 4.3-1.)

   The base-part cost, thus, is: (9.66)1.30 + 1.80 = 14.36 man-hours per part.

5. Check for applicable DICE. This part has strip plies. The Format Selection Aid indicates that format DICE-G/E-1 (Figure 4.3-5) must be used. This format requires length (ft), number of plies, and width (in.) of each ply. These values are:

   - Length = 7 ft
   - Number of plies = 10
   - Width = 1.5 in.

   From the format, the cost of the strip plies is 0.6 man-hours per part.

6. Determine the total manufacturing cost for the part (excluding direct material cost) which is the sum of base-part cost and the cost of strip plies (0.6) times the learning curve factor (1.30): 14.36 + (0.6) 1.30 = 15.14 man-hours per part.

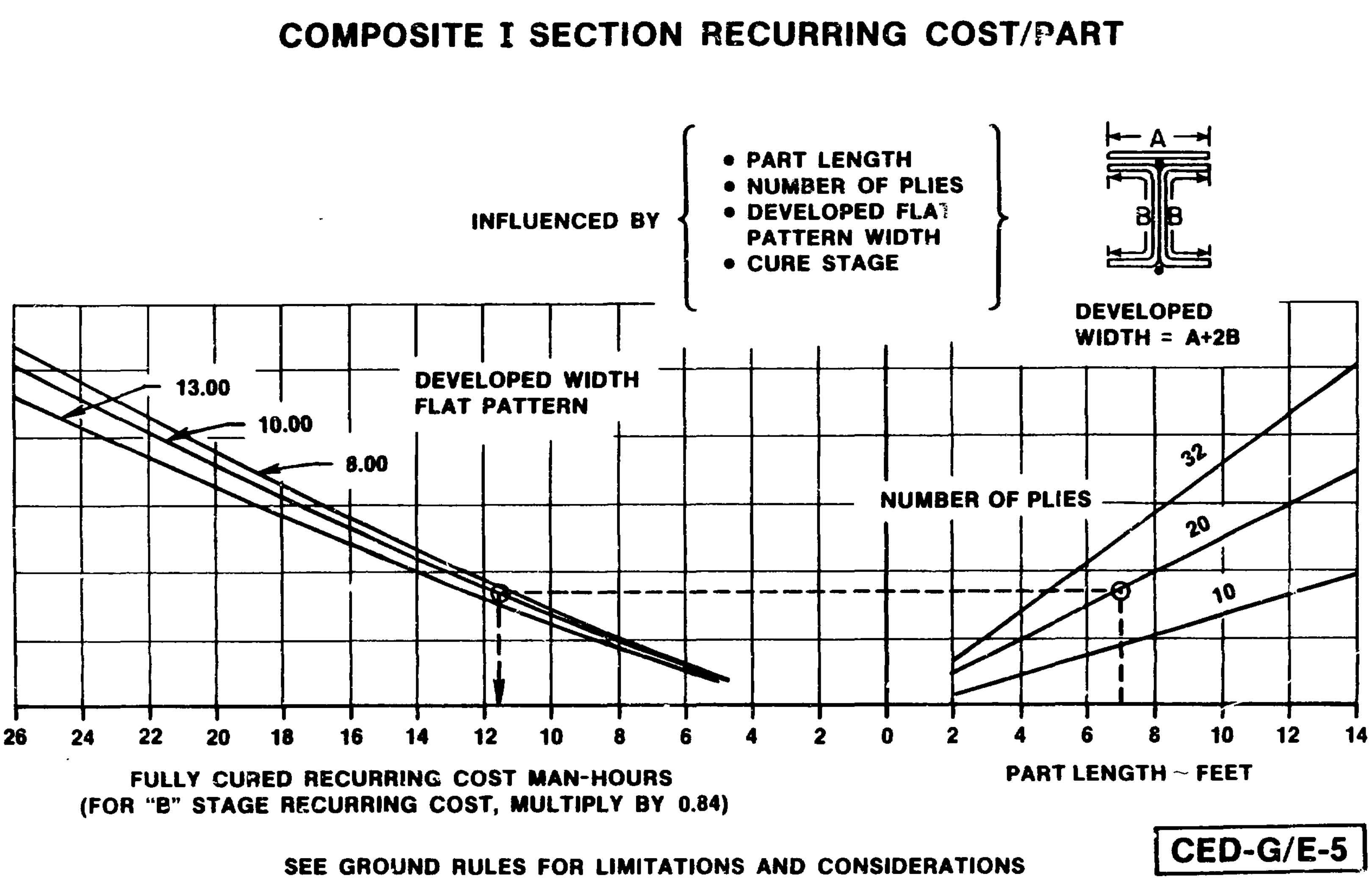
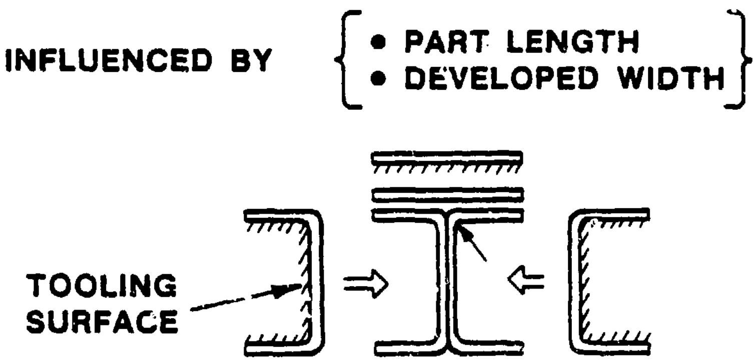
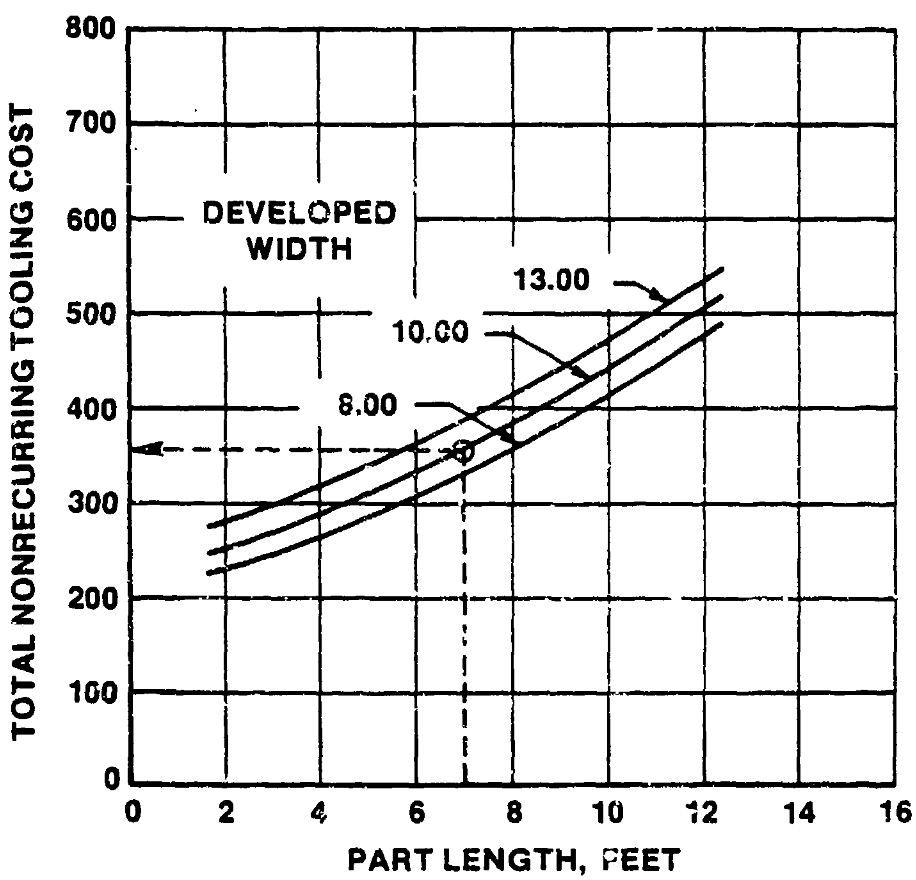


FIGURE 4.3-3. FORMAT USED IN EXAMPLE

COMPOSITE I SECTION
TOTAL NONRECURRING TOOLING COST/PART





SEE GROUND RULES FOR LIMITATIONS AND CONSIDERATIONS

FIGURE 4.3-4. FORMAT USED IN EXAMPLE

CED-G/E-6

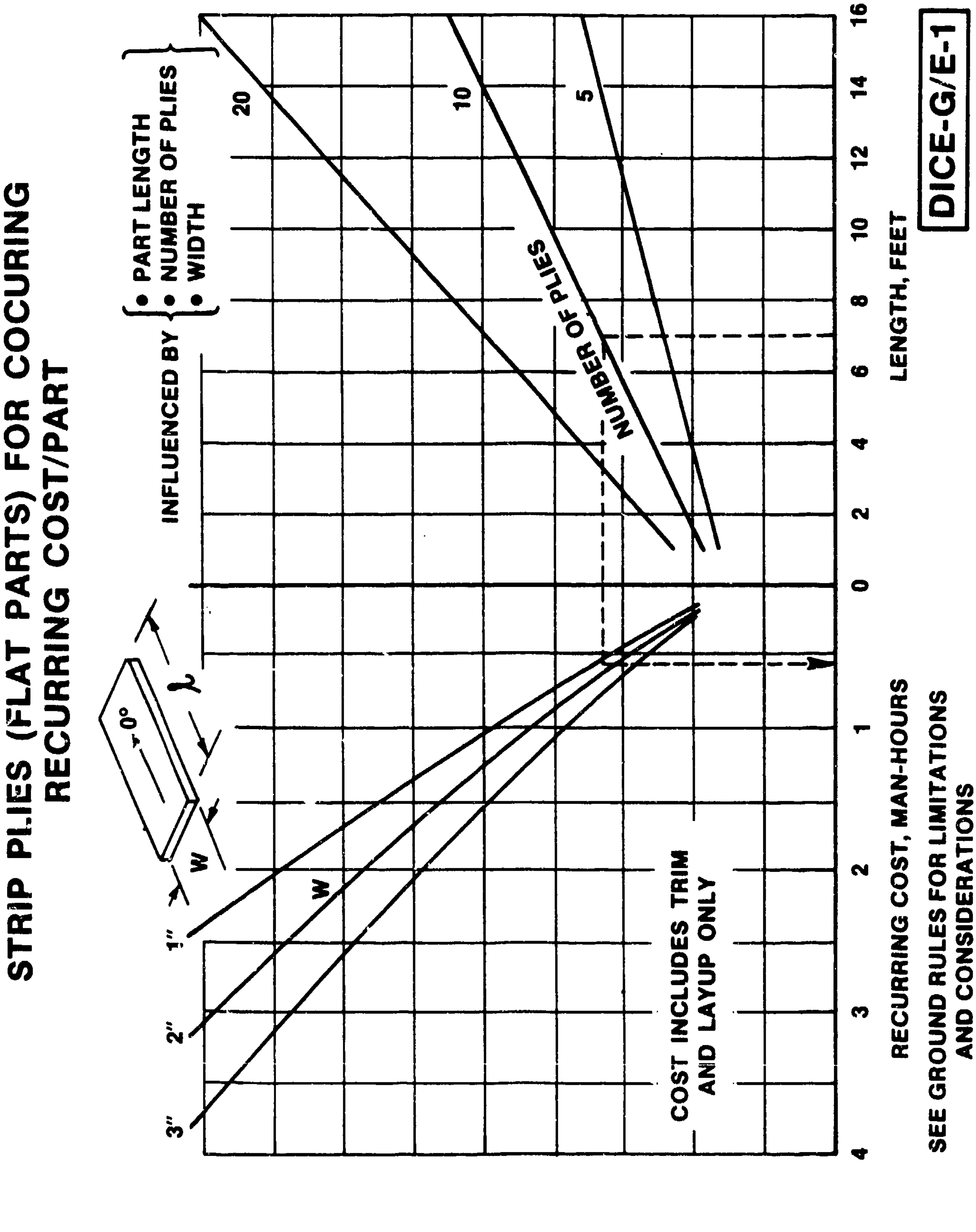


FIGURE 4.3-5. FORMAT USED IN EXAMPLE

TABLE 4.3-1.

FACTORS TO CONVERT THE MC/DG 200TH UNIT COST TO THE CUMULATIVE AVERAGE COST FOR THE DESIGN QUANTITY AND LEARNING CURVE INVOLVED

DESIGN QUANTITY	LEARNING CURVE-%						
	95	90	85	80	75	70	65
1	1.48	2.25	3.48	5.50	9.00	15.00	27.00
10	1.33	1.79	2.47	3.48	5.04	7.53	11.67
25	1.25	1.59	2.05	2.71	3.68	5.13	7.43
50	1.19	1.44	1.79	2.22	2.85	3.76	5.14
100	1.13	1.30	1.52	1.80	2.18	2.73	3.51
200	1.08	1.17	1.30	1.45	1.66	1.95	2.36
350	1.04	1.08	1.14	1.22	1.33	1.48	1.70
500	1.01	1.02	1.05	1.09	1.15	1.24	1.38
750	0.98	0.96	0.96	0.96	0.97	1.01	1.09
1000	0.96	0.92	0.89	0.87	0.87	0.88	0.91

4.3.3 Parts Analyzed

The cost-driver effect and manufacturing man-hour data were derived analyzing the discrete parts shown in Figures 4.8-6 and 4.8-7. It will be noted that lineal shapes and panels are included. The ground rules on which the data were based is included in Section 4.3.5.

The parts were also utilized to derive the test, inspection and evaluation (TI&E) data included in Section 4.7.

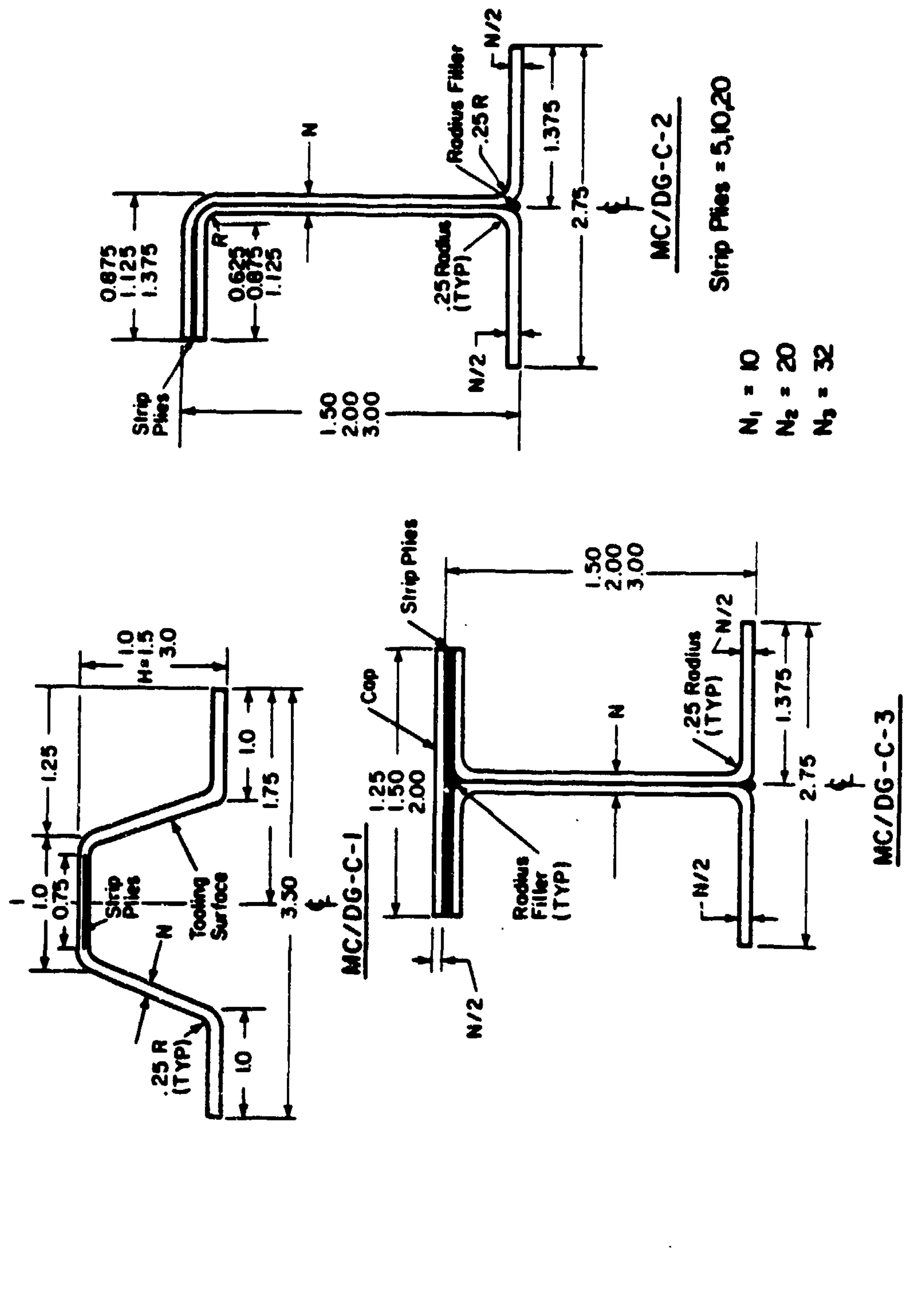


FIGURE 4.3-6. COMPOSITE LINEAL SHAPES ANALYZED TO DEVELOP FORMATS

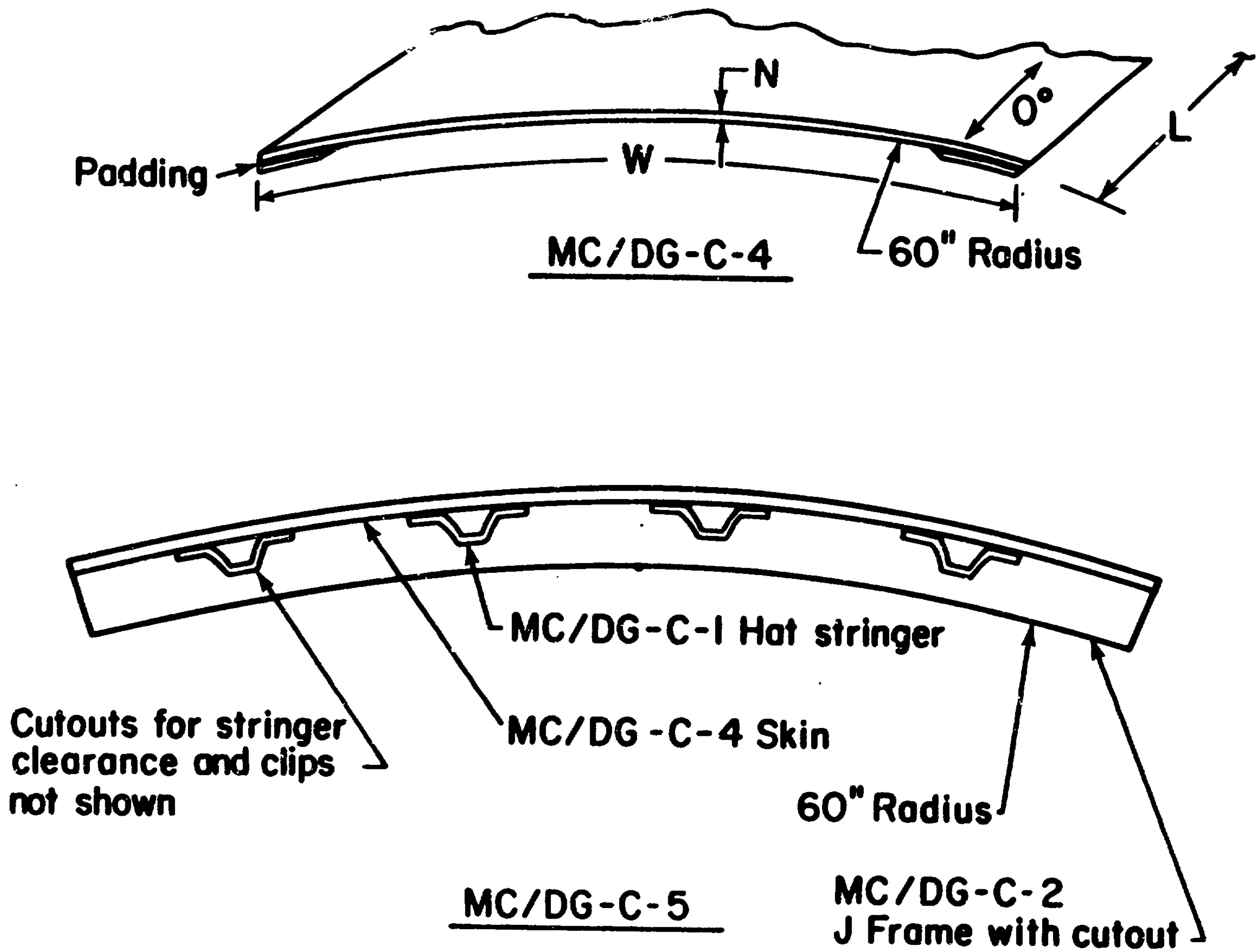
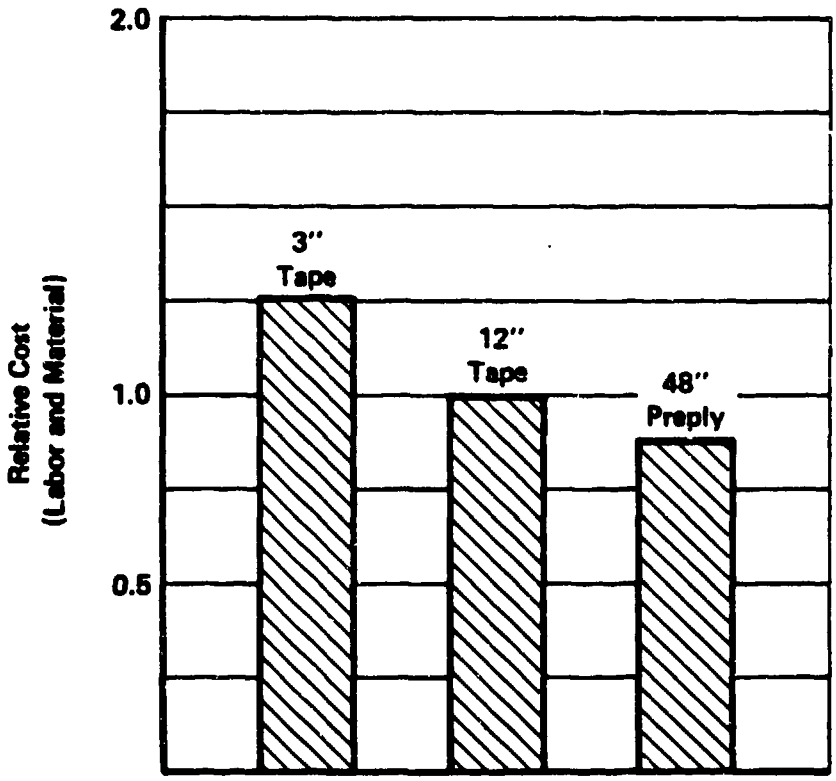


FIGURE 4.3-7. COMPOSITE PANELS ANALYZED TO DEVELOP MC/DG FORMATS

4.3.4 Composite Materials Data

Data/formats on the following pages identify generic part shapes studied and provide the applicable cost curves and charts for conducting cost trade studies.

EFFECT OF MATERIAL FORM ON LAYUP COST



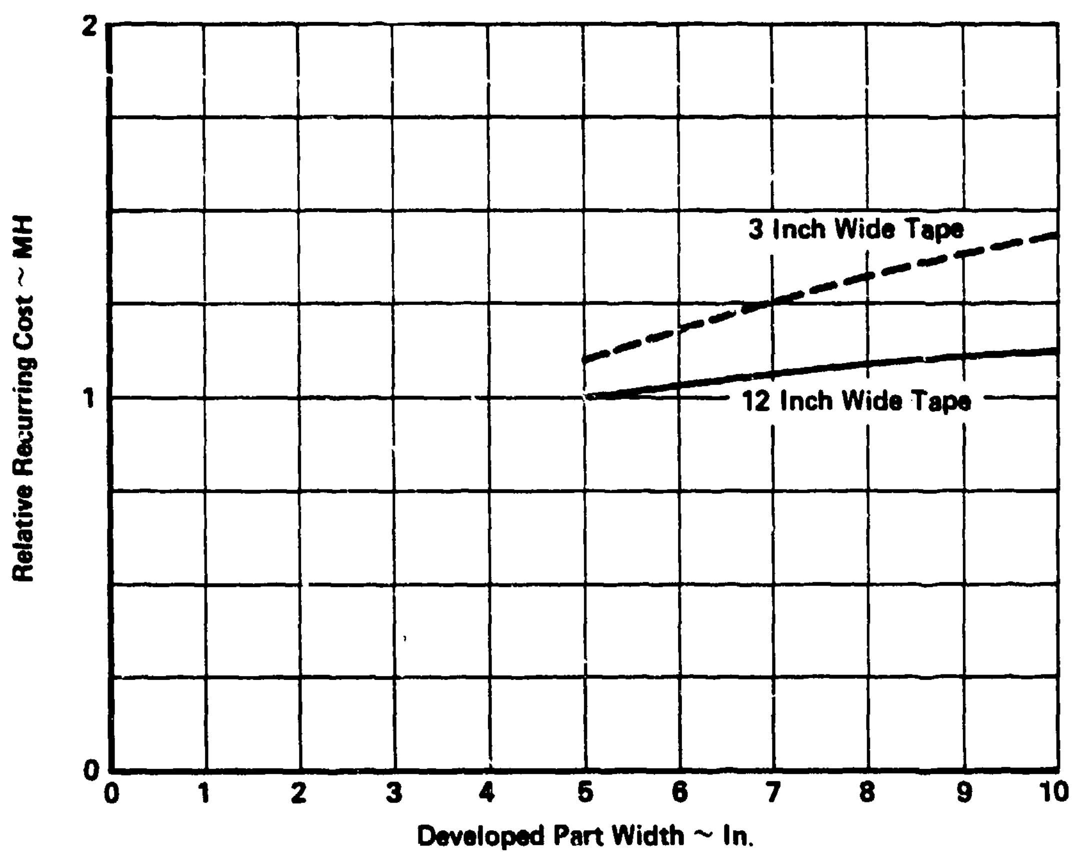
LAMINATE SIZE: 48" x 144"

CDE-G/E-I

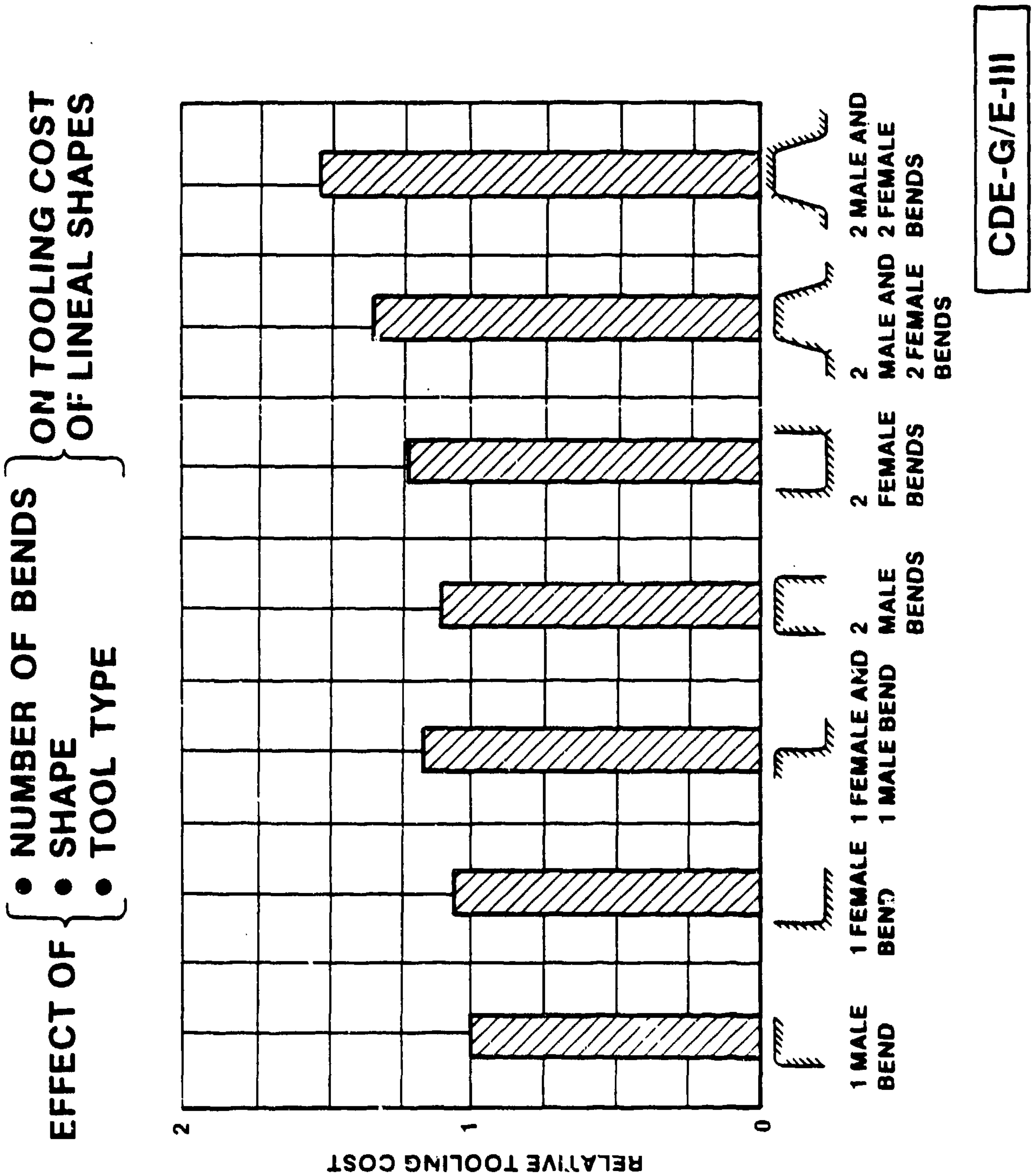
EFFECT OF TAPE WIDTH ON COST OF LINEAL SHAPES

Notes:

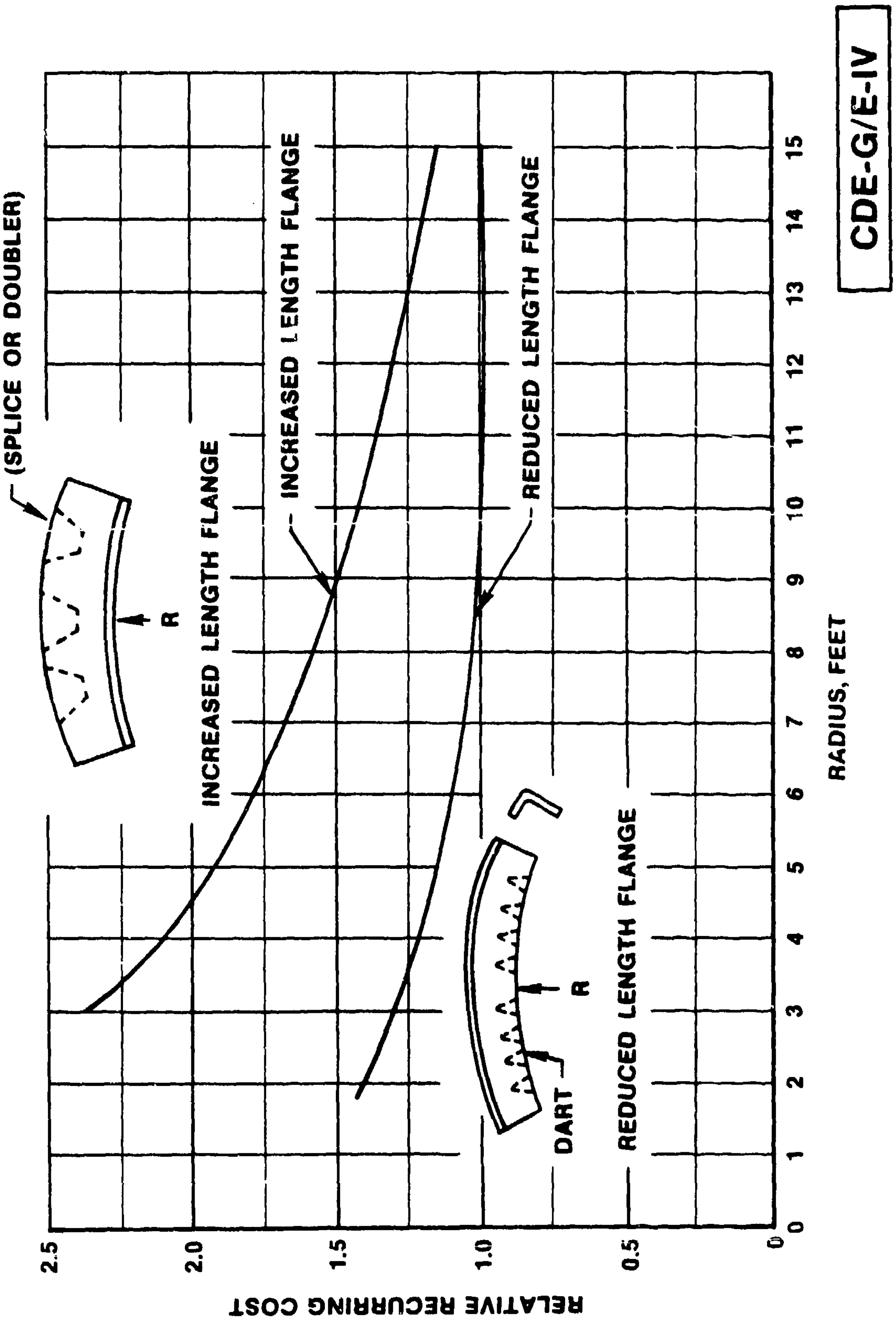
- Part Length = 48"
- No Strip Plies



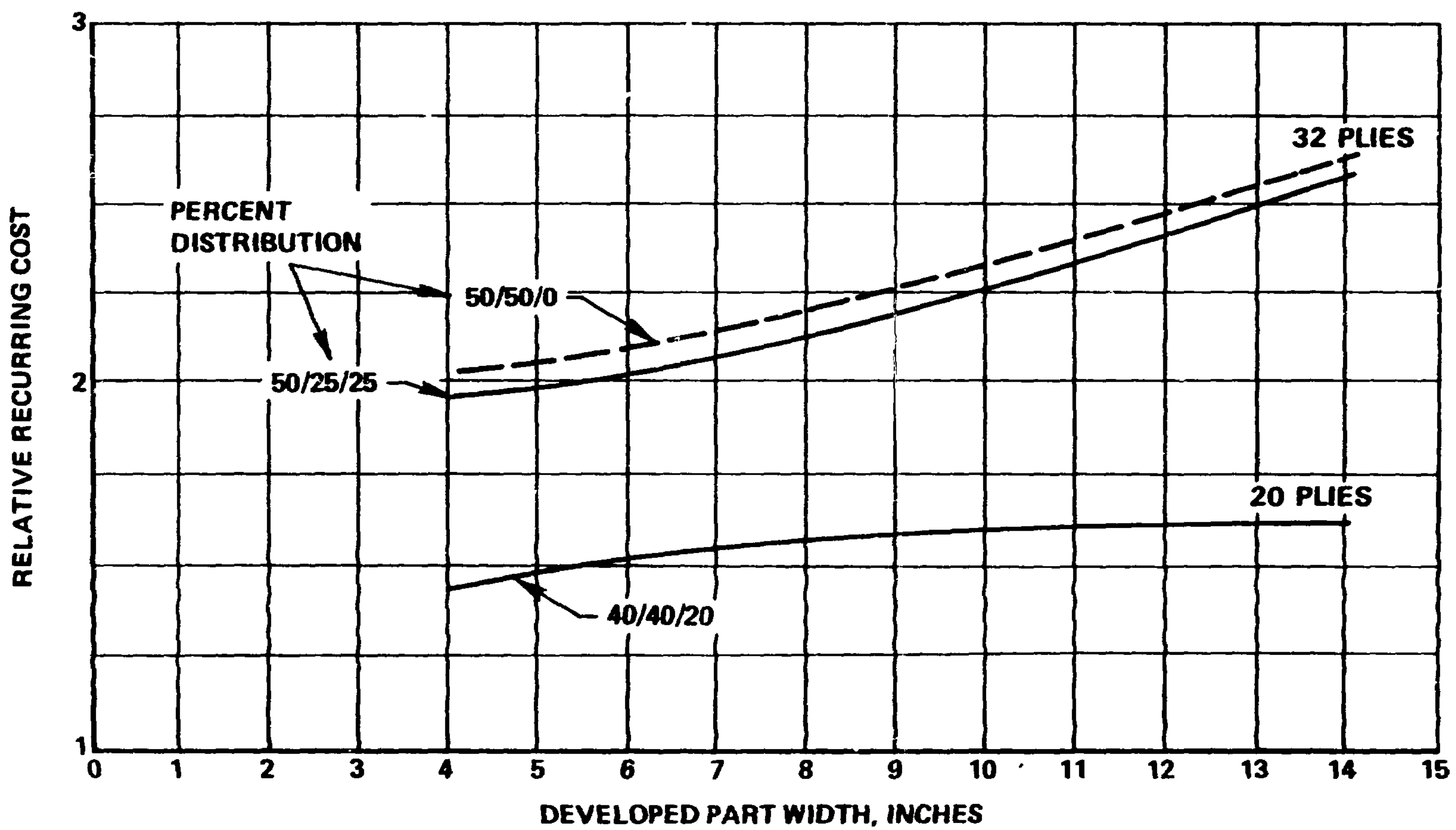
CDE-G/E-11


EFFECT OF
• NUMBER OF BENDS
• SHAPE
• TOOL TYPE
ON TOOLING COST OF LINEAL SHAPES
RELATIVE TOOLING COST
0
1
2
1 MALE BEND
1 FEMALE BEND
1 FEMALE AND 1 MALE BEND
2 MALE BENDS
2 FEMALE BENDS
2 MALE AND 2 FEMALE BENDS
2 MALE AND 2 FEMALE BENDS
CDE-G/E-III

EFFECT OF RADIUS OF CURVATURE ON RECURRING COST OF LINEAL SHAPES



EFFECT OF { • NO. OF PLIES* • PLY ORIENTATION • DEVELOPED WIDTH } ON RECURRING COST OF LINEAL HAT SECTION

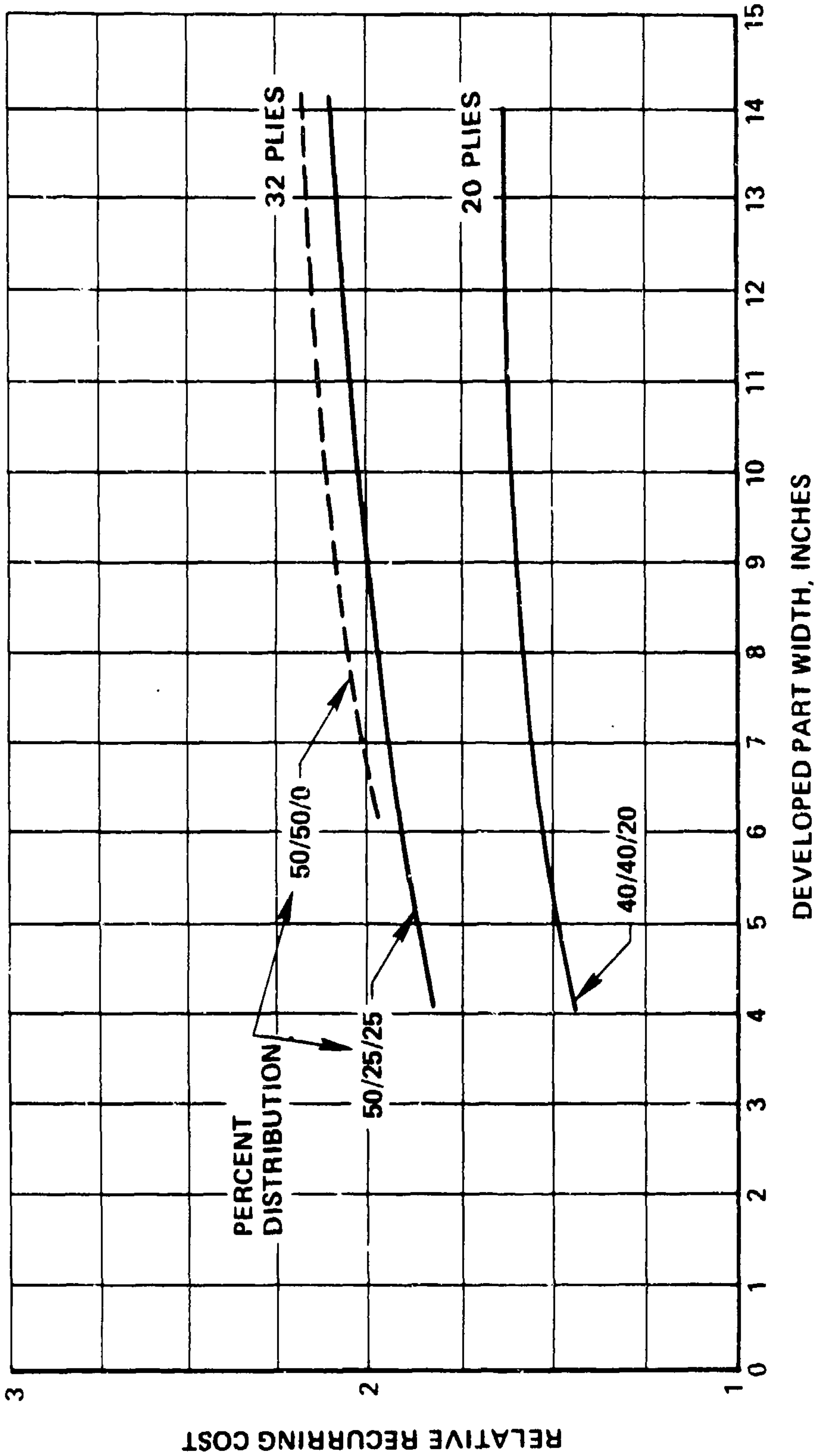


*PLY ORIENTATION CODE:
0°/±45°/90°

CDE-G/E-V

EFFECT OF
- NO. OF PLIES*
- PLY ORIENTATION
- DEVELOPED WIDTH

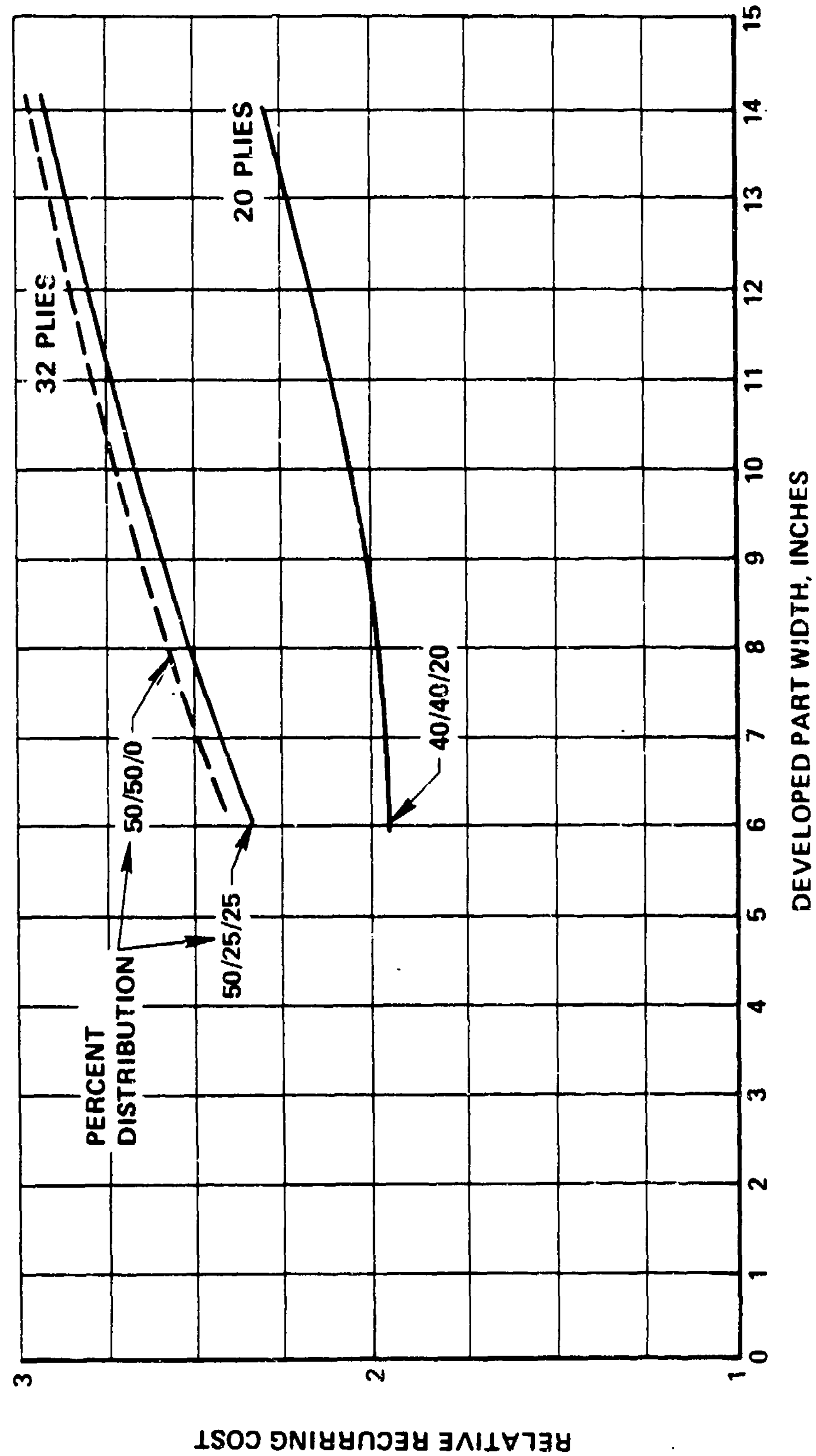
ON RECURRING COST OF LINEAL "J" SECTION



CDE-G/E-VI

*PLY ORIENTATION CODE:
0°/±45°/90°

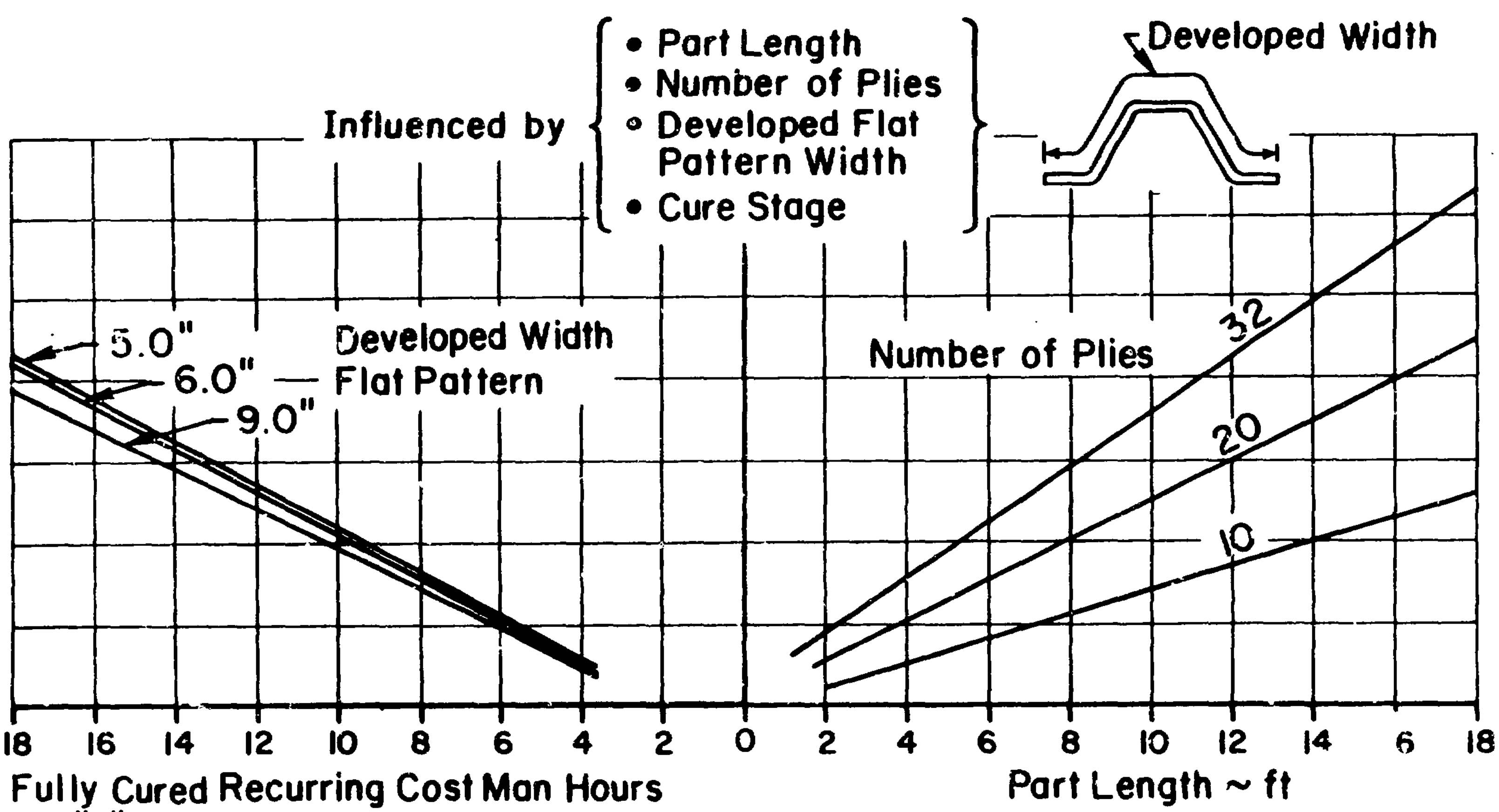
EFFECT OF { • NO. OF PLIES* • PLY ORIENTATION • DEVELOPED WIDTH } ON RECURRING COST OF LINEAL "I" SECTION



*PLY ORIENTATION CODE:
0°/±45°/90°

CDE-G/E-VII

COMPOSITE HAT SECTION RECURRING COST/PART

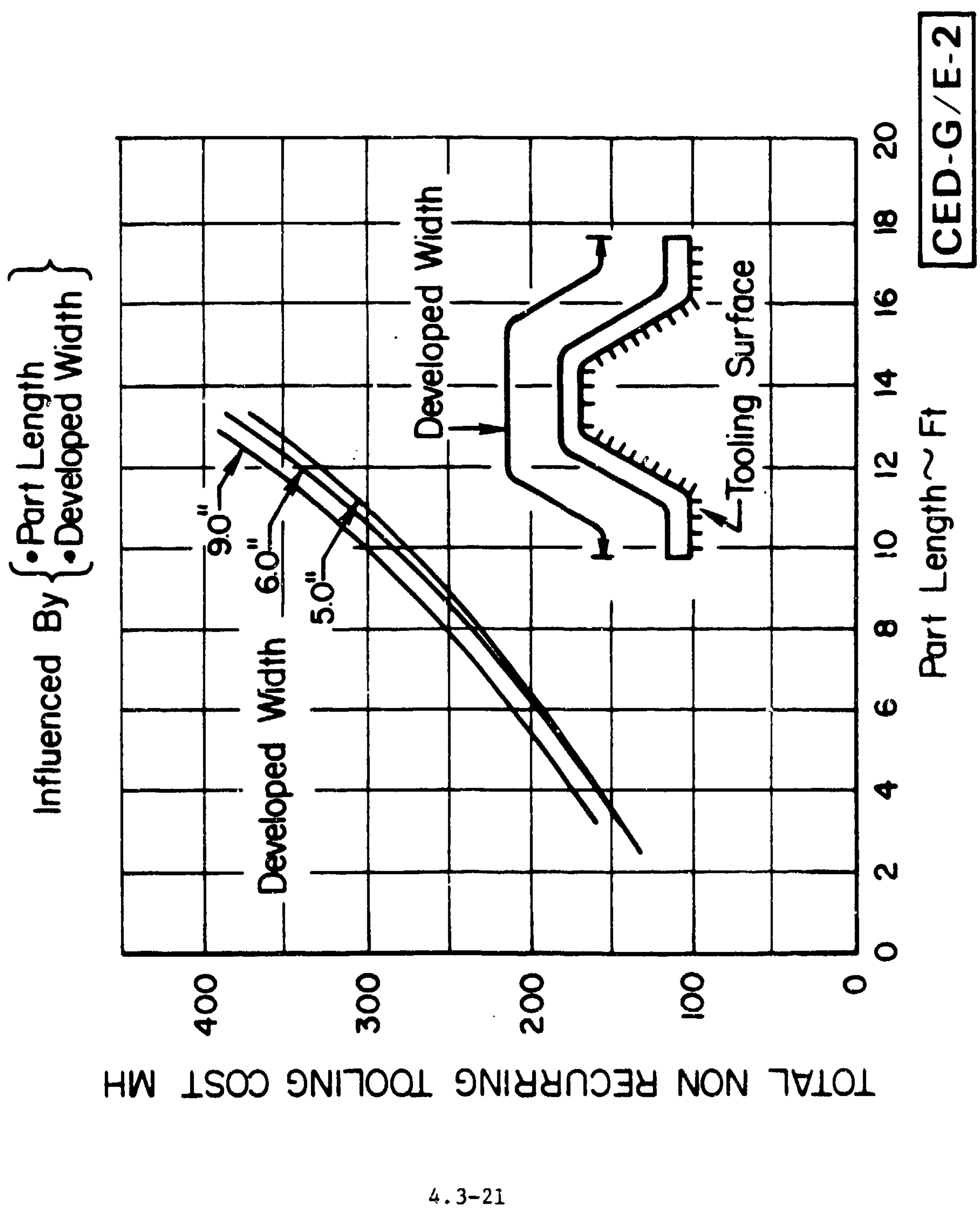


For "B" Staged Recurring Cost, Multiply by 0.84

See Ground Rules for Limitations and Considerations

CED-G/E-1

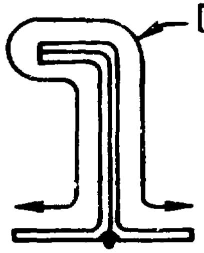
COMPOSITE HAT SECTION TOTAL NONRECURRING TOOLING COST/PART

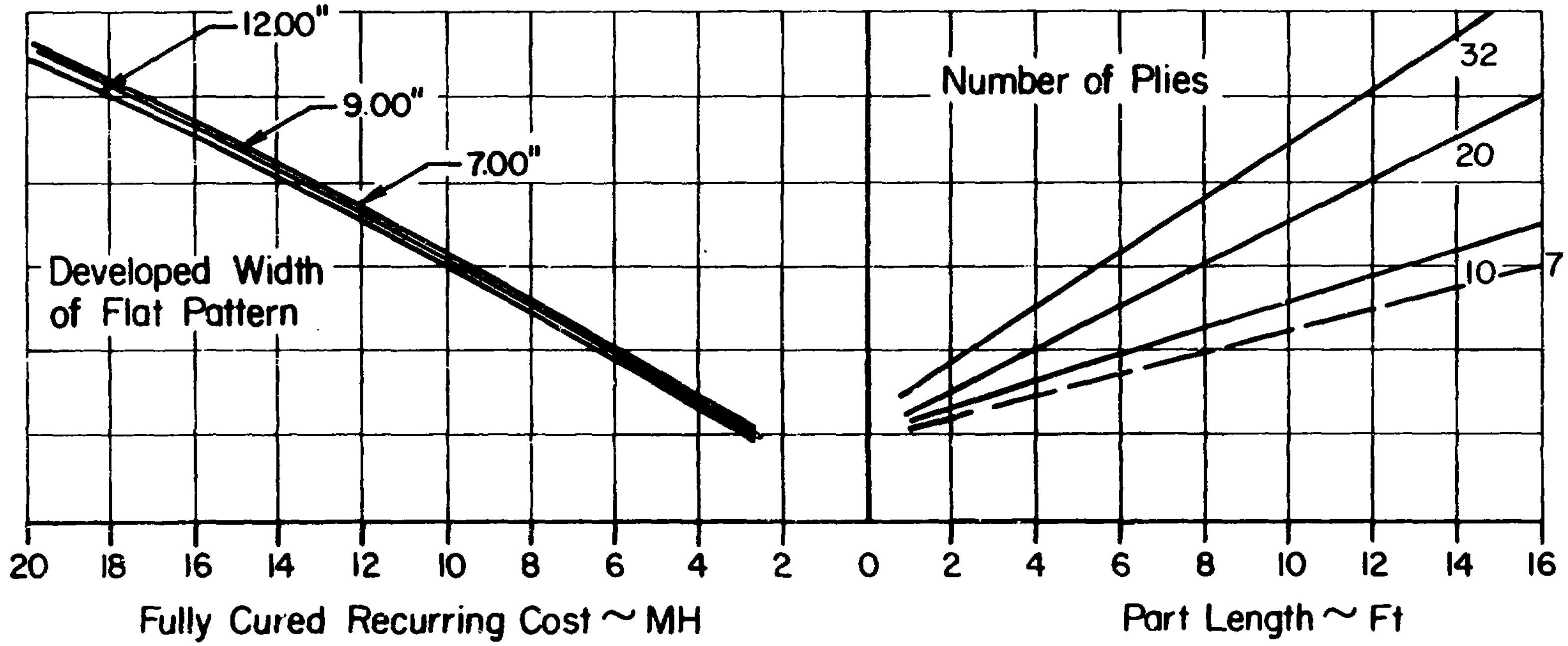


See Ground Rules for Limitations and Considerations

COMPOSITE J SECTION RECURRING COST/PART

Influenced By
- Part Length
- Number of Plies
- Developed Flat Pattern Width
- Cure Stage



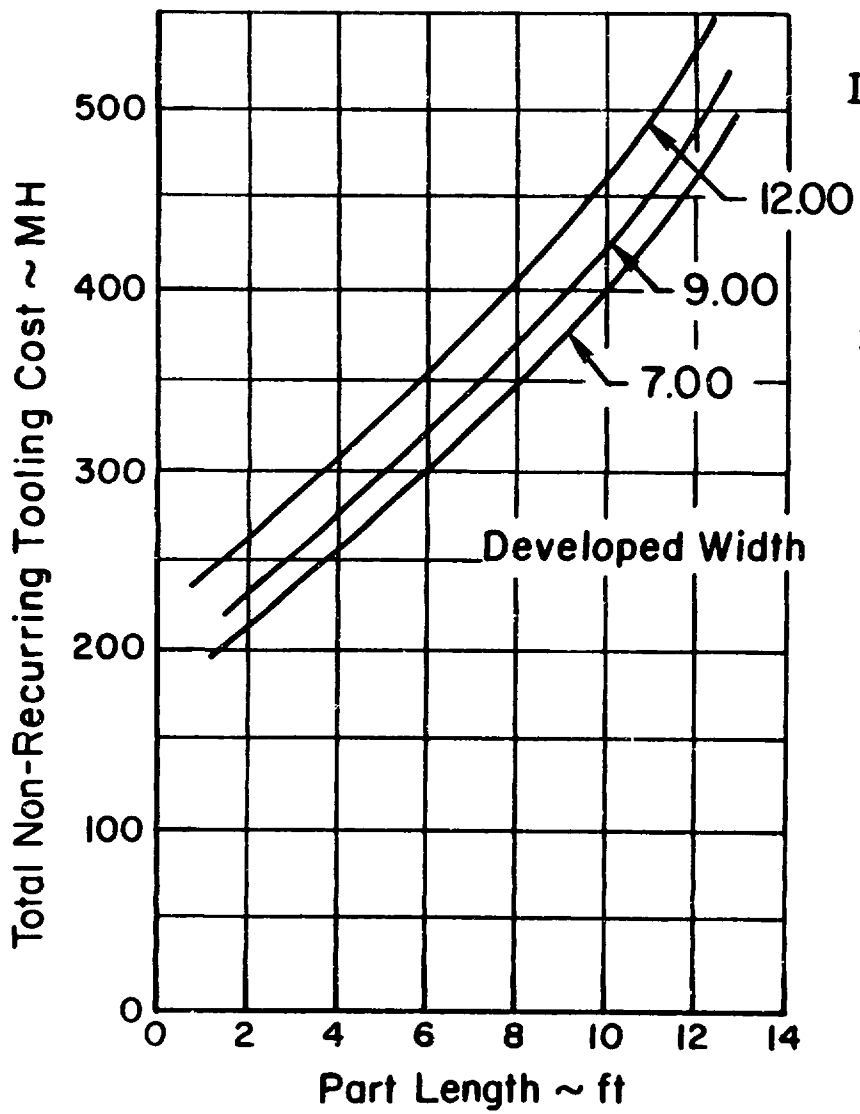


For "B" Stage Recurring Cost, Multiply by 0.84

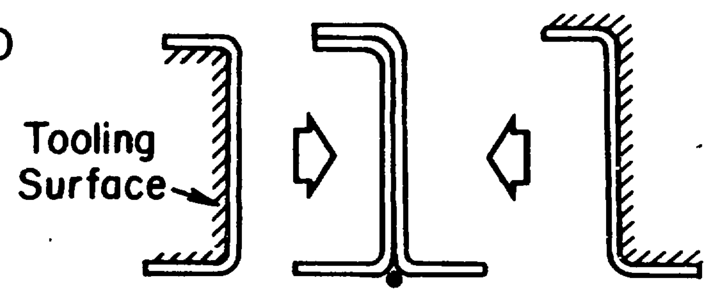
See Ground Rules for Limitations and Considerations

CED-G/E-3

COMPOSITE J SECTION TOTAL NON-RECURRING TOOLING COST/PART



Influenced by { • Part Length • Developed Width }

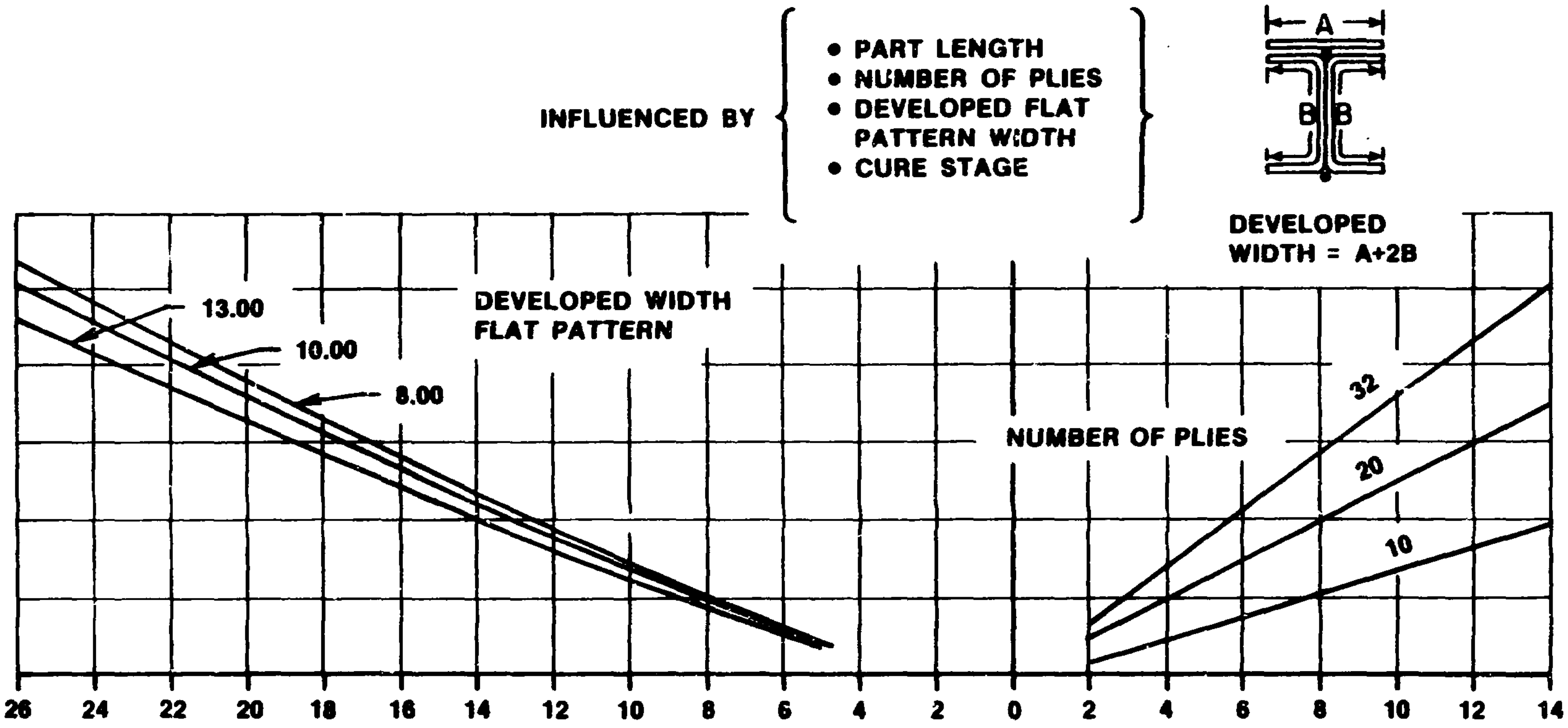


See Ground Rules for Limitations and Considerations

CED-G/E-4

FTR450261000U
3 Jan 1983

COMPOSITE I SECTION RECURRING COST/PART

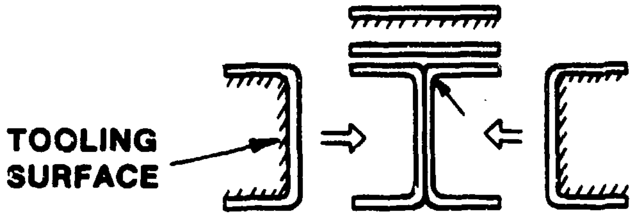


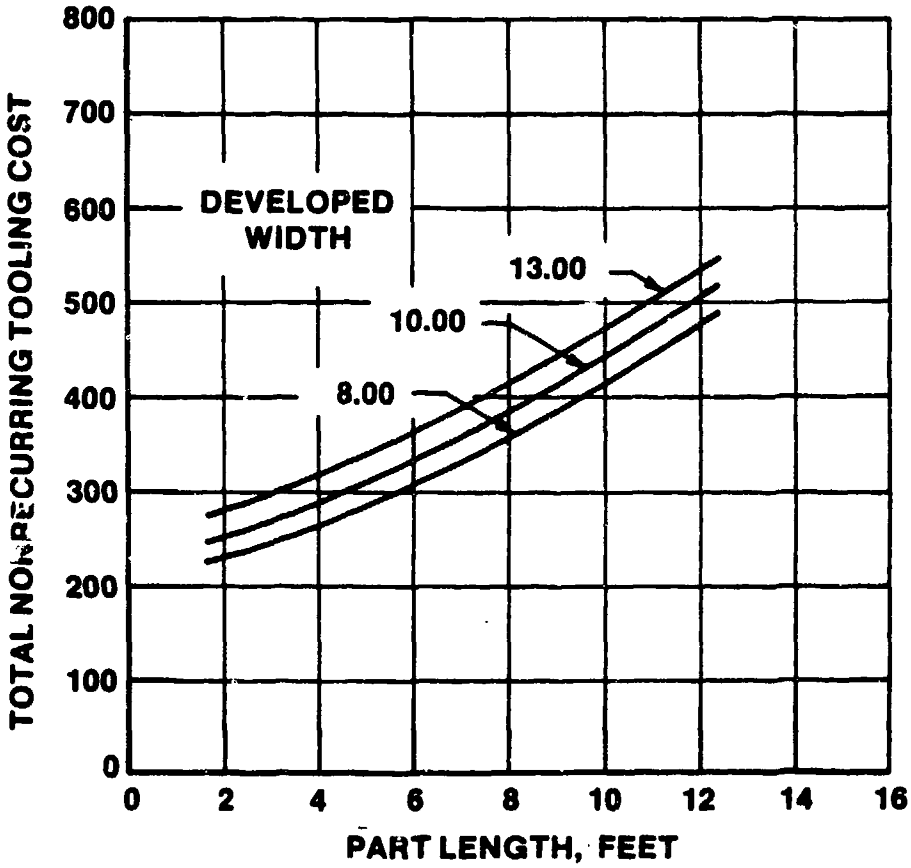
SEE GROUND RULES FOR LIMITATIONS AND CONSIDERATIONS

CED-G/E-5

COMPOSITE I SECTION
TOTAL NONRECURRING TOOLING COST/PART

INFLUENCED BY { • PART LENGTH • DEVELOPED WIDTH }



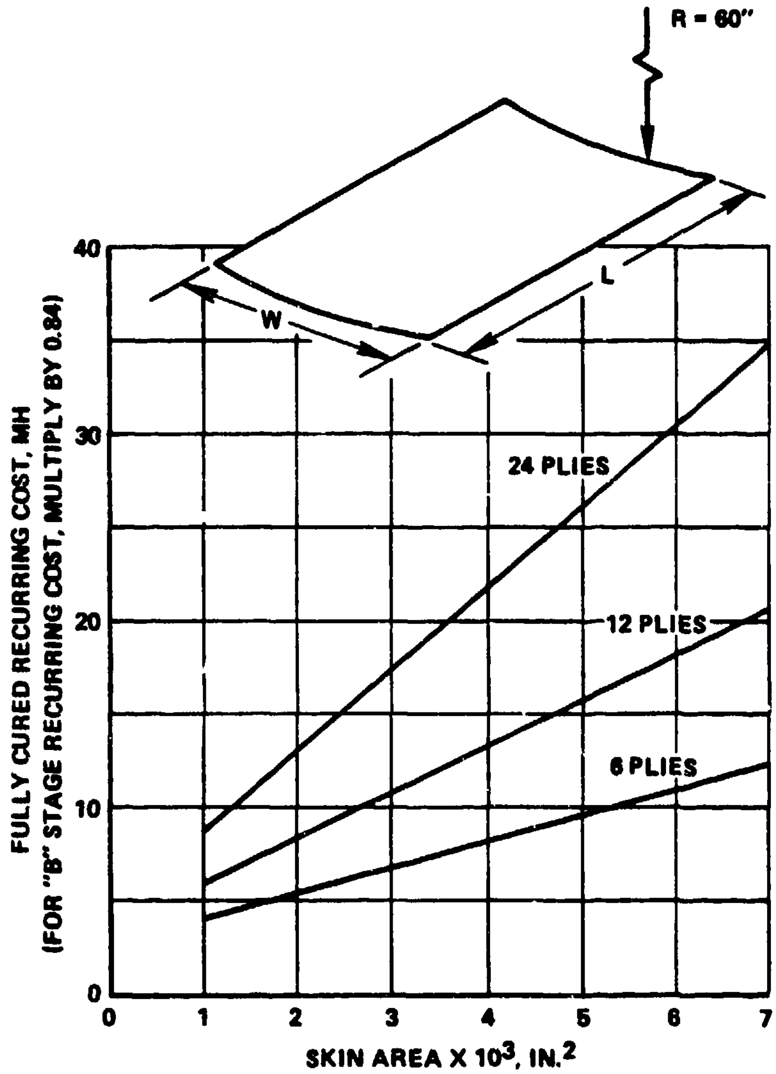


SEE GROUND RULES FOR LIMITATIONS AND CONSIDERATIONS

CED-G/E-6

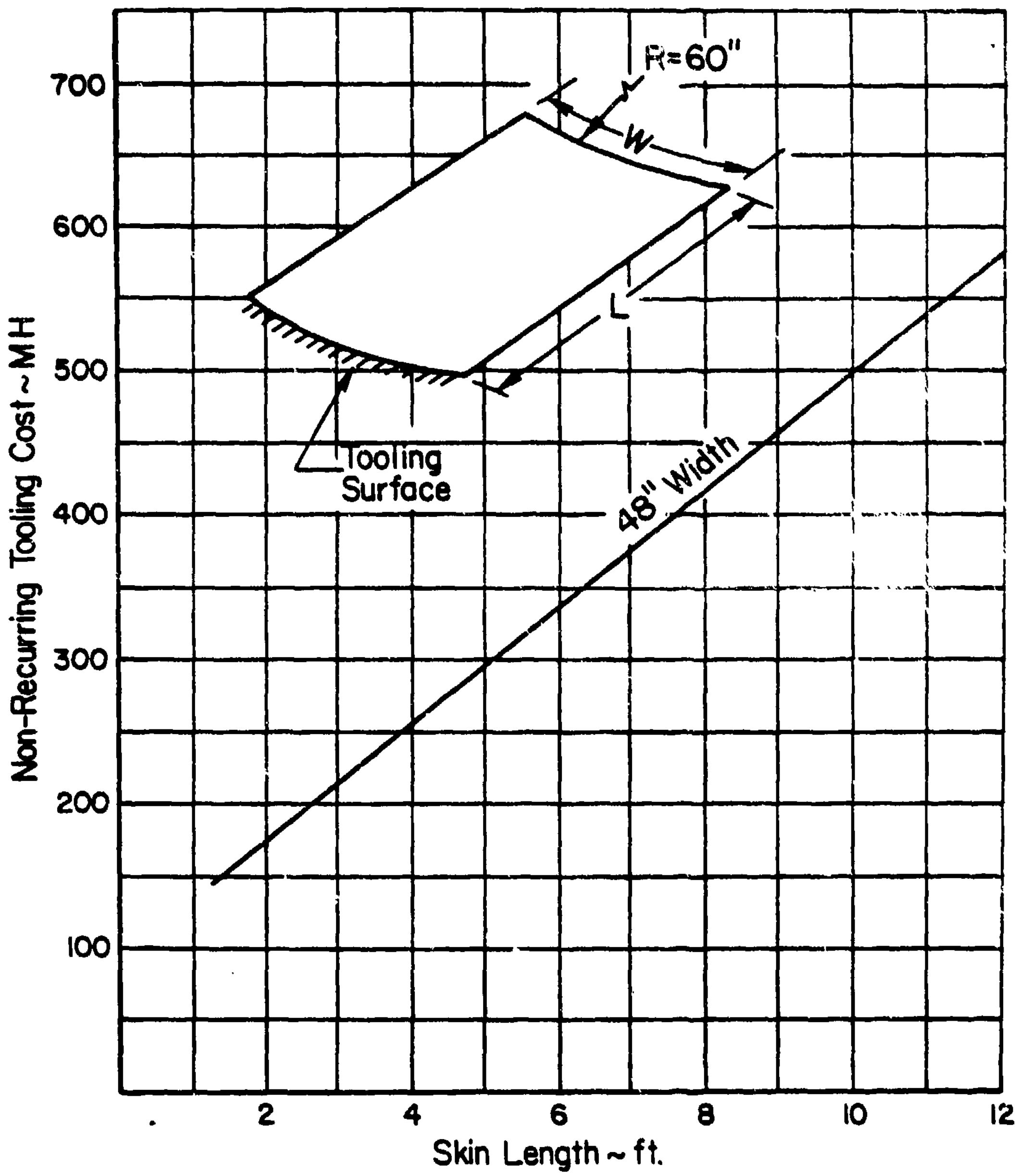
SINGLE CURVATURE SKIN RECURRING COST/PART

INFLUENCED BY
- AREA
- NUMBER OF PLIES
- CURE STAGE



CED-G/E-7

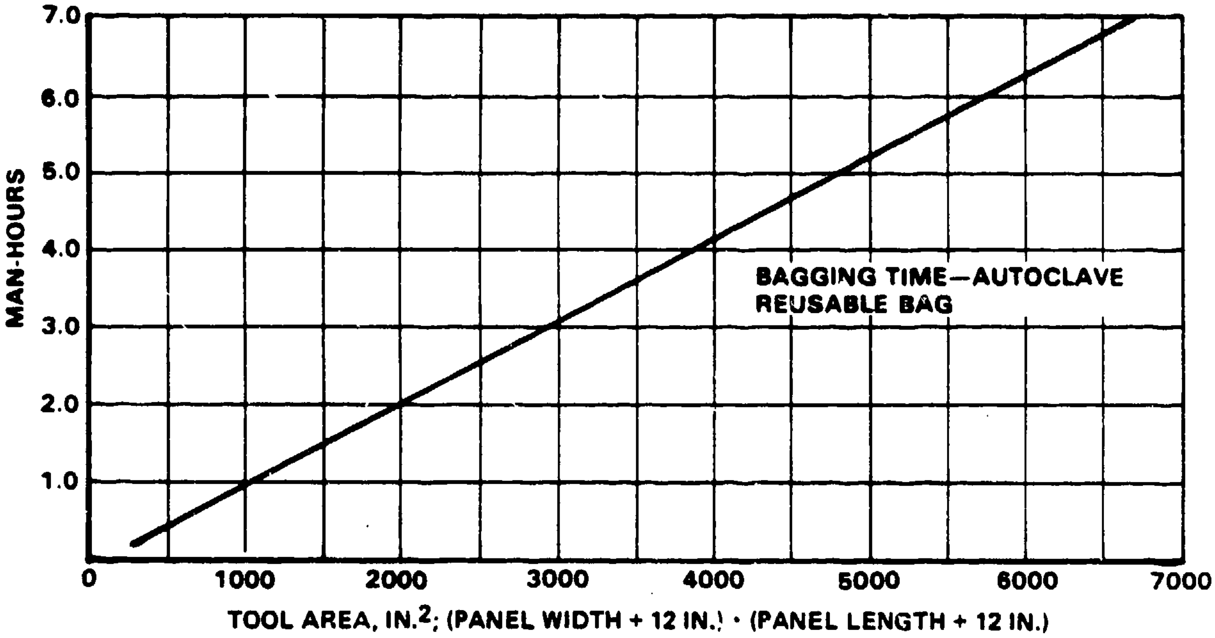
SINGLE CURVATURE SKIN NON-RECURRING TOOLING COST/PART

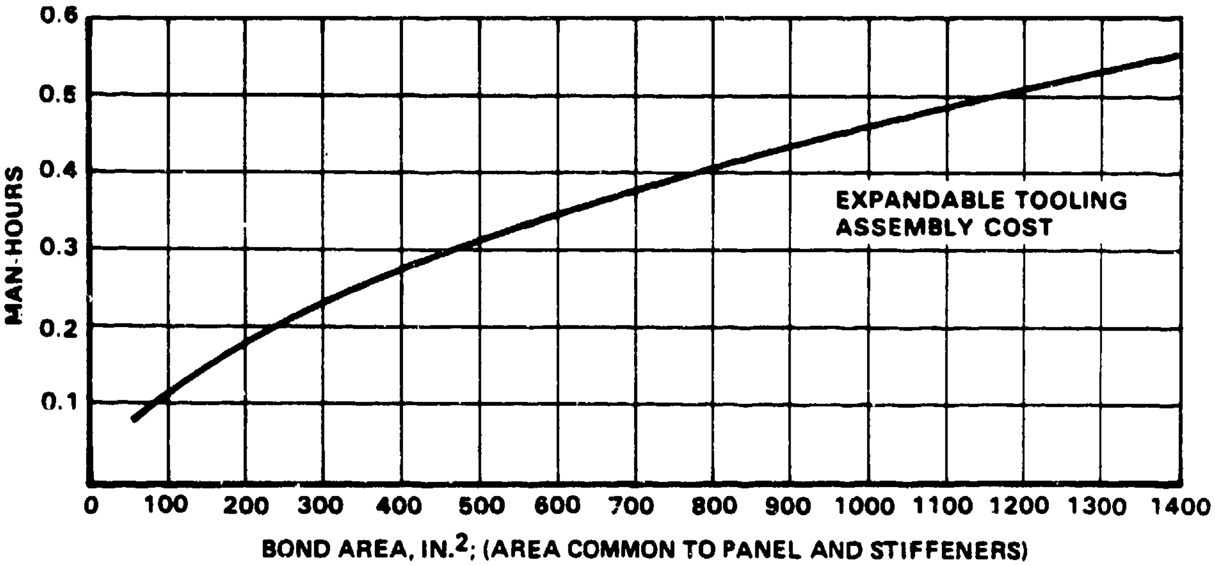


See Ground Rules for Limitations and Considerations

CED-G/E-8

ASSEMBLY TIME—COCURED PANEL



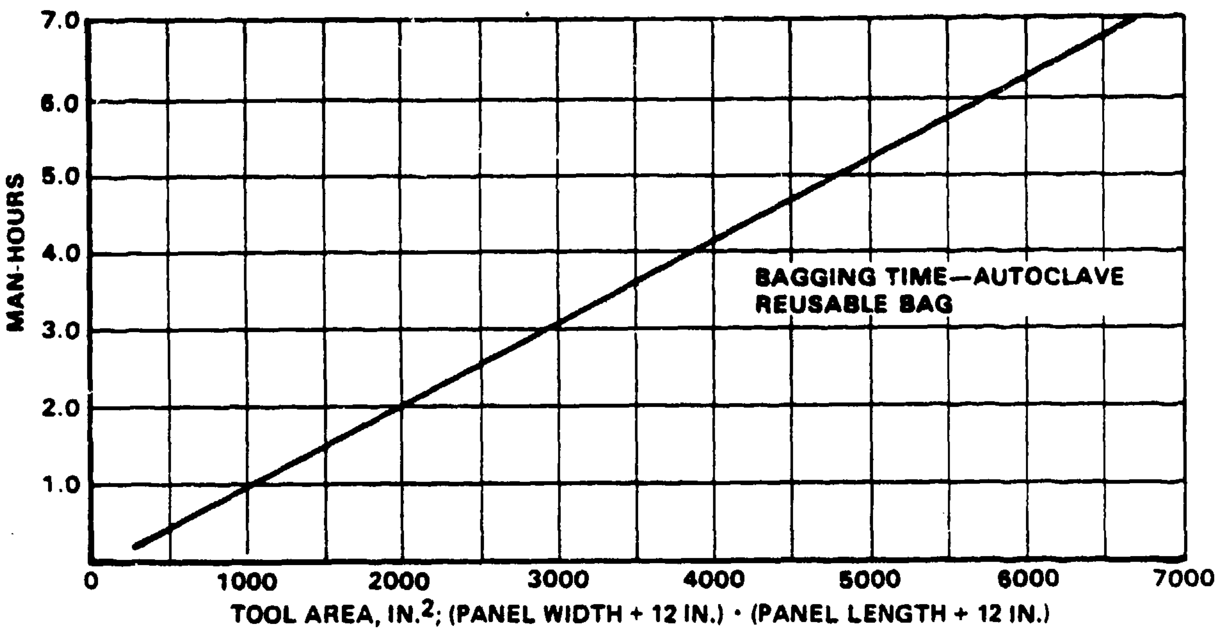


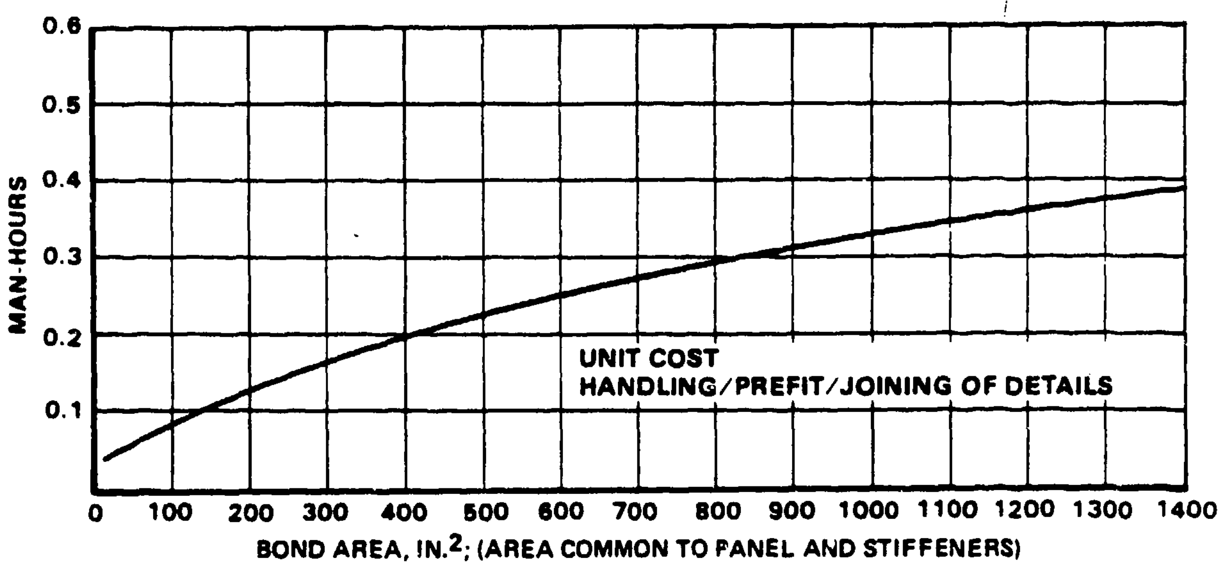
Notes: (1) To determine recurring cost of assembly and bond of fully cured skin and stiffener details, use both CED-G/E-10 formats and both CED-G/E-9 formats.

(2) Tool made for panel (CED-G/E-8) also used for these operations.

CED-G/E-9

ASSEMBLY TIME



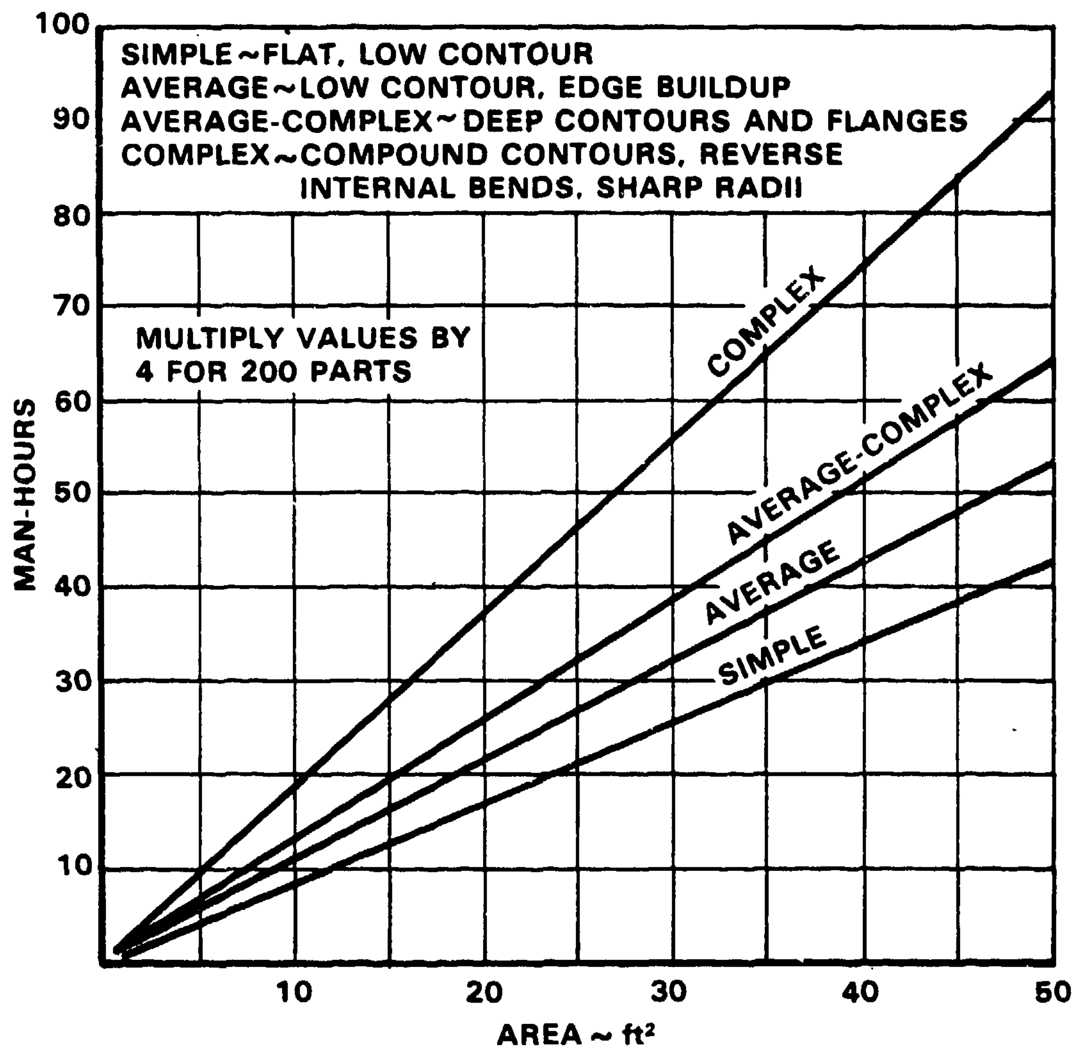


Notes: (1) To determine recurring cost of assembly and bond of fully cured skin and stiffener details, use both CED-G/E-10 formats and both CED-G/E-9 formats.

(2) Tool made for panel (CED-G/E-8) also used for these operations.

CED-G/E-10

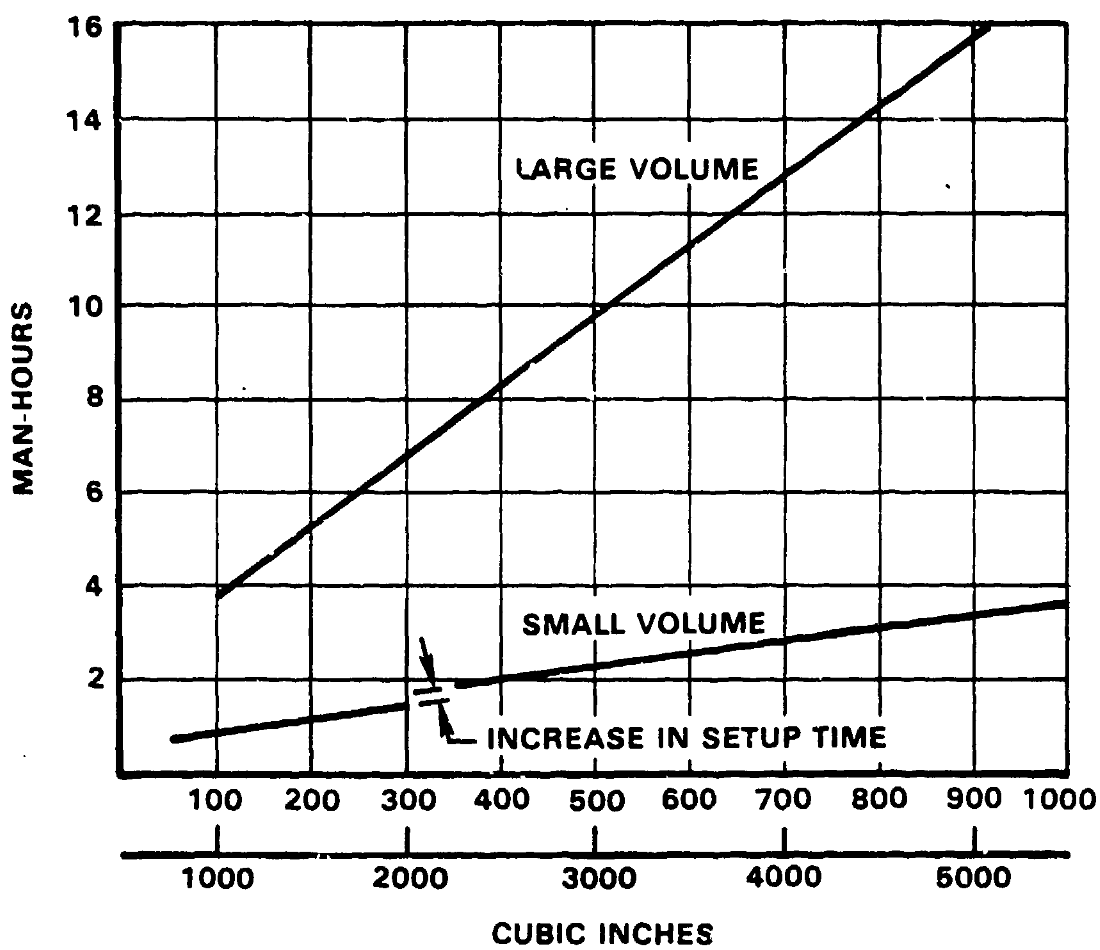
NON-RECURRING TOOLING COST
REUSABLE RUBBER BAGS



CED-G/E-11

FTR450261000U
3 Jan 1983

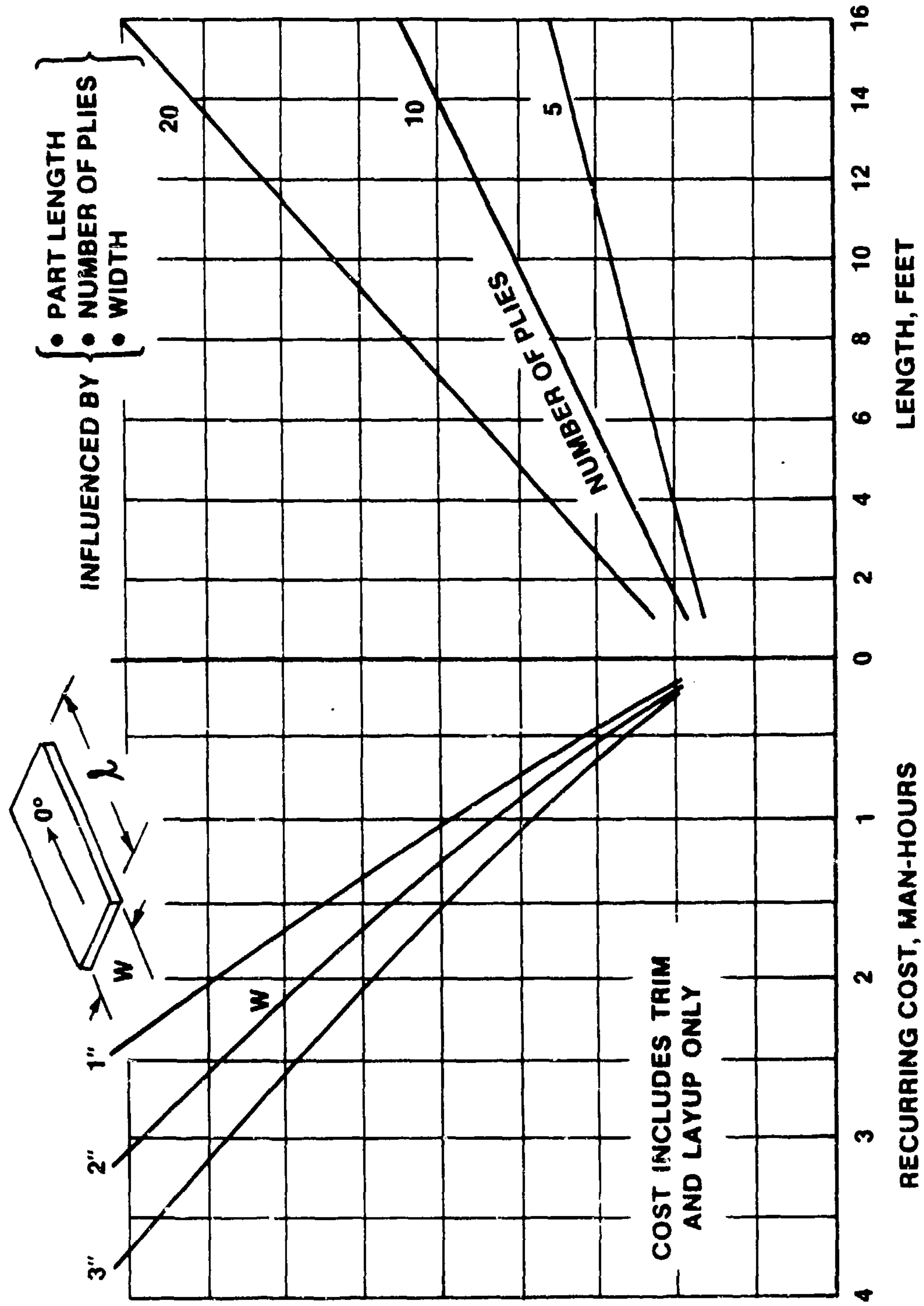
NON-RECURRING TOOLING COST SILASTIC PLUGS



CED-G/E-12

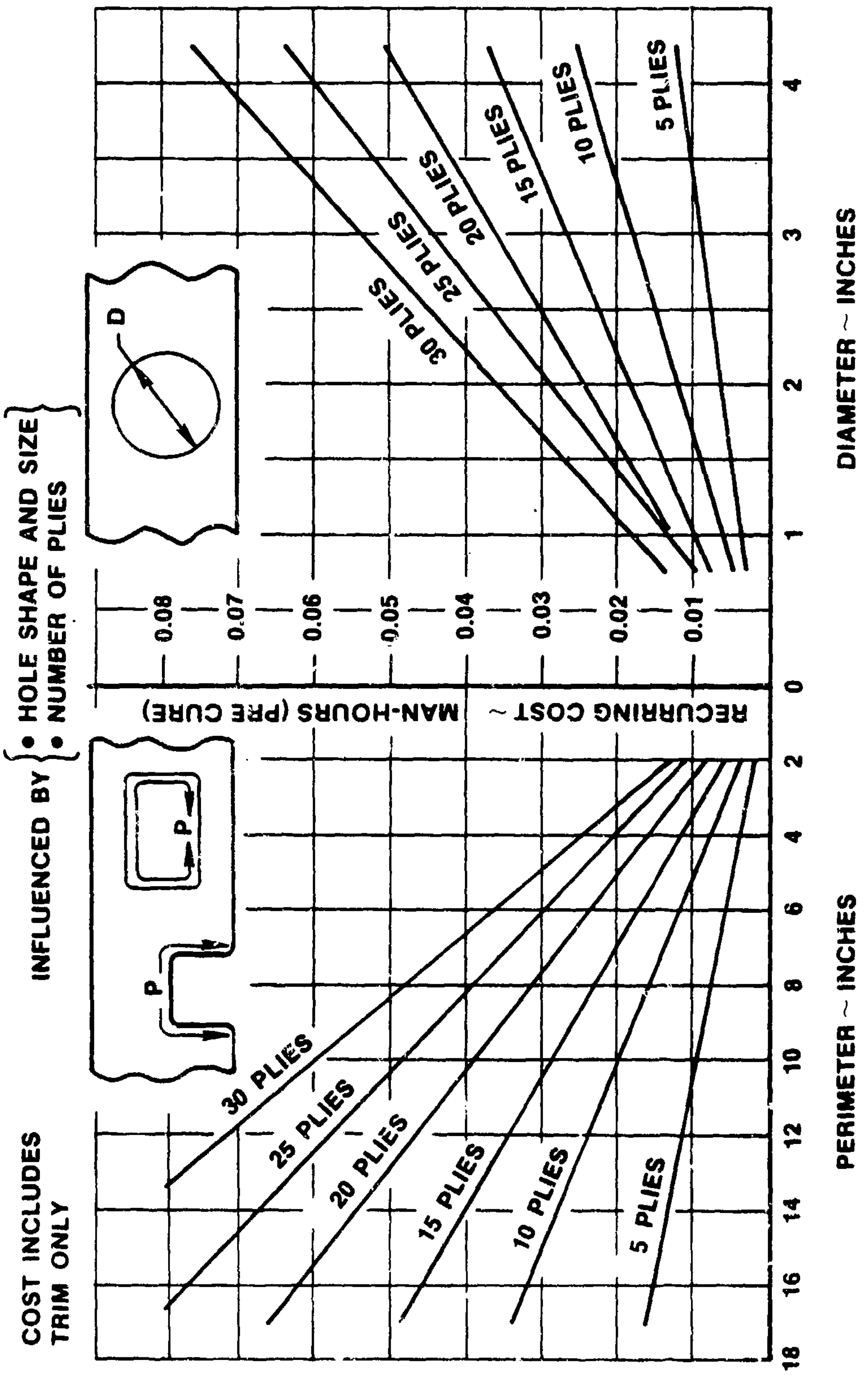
DICE-G/E-1

STRIP PLIES (FLAT PARTS) FOR COCURING RECURRING COST/PART



SEE GROUND RULES FOR LIMITATIONS AND CONSIDERATIONS

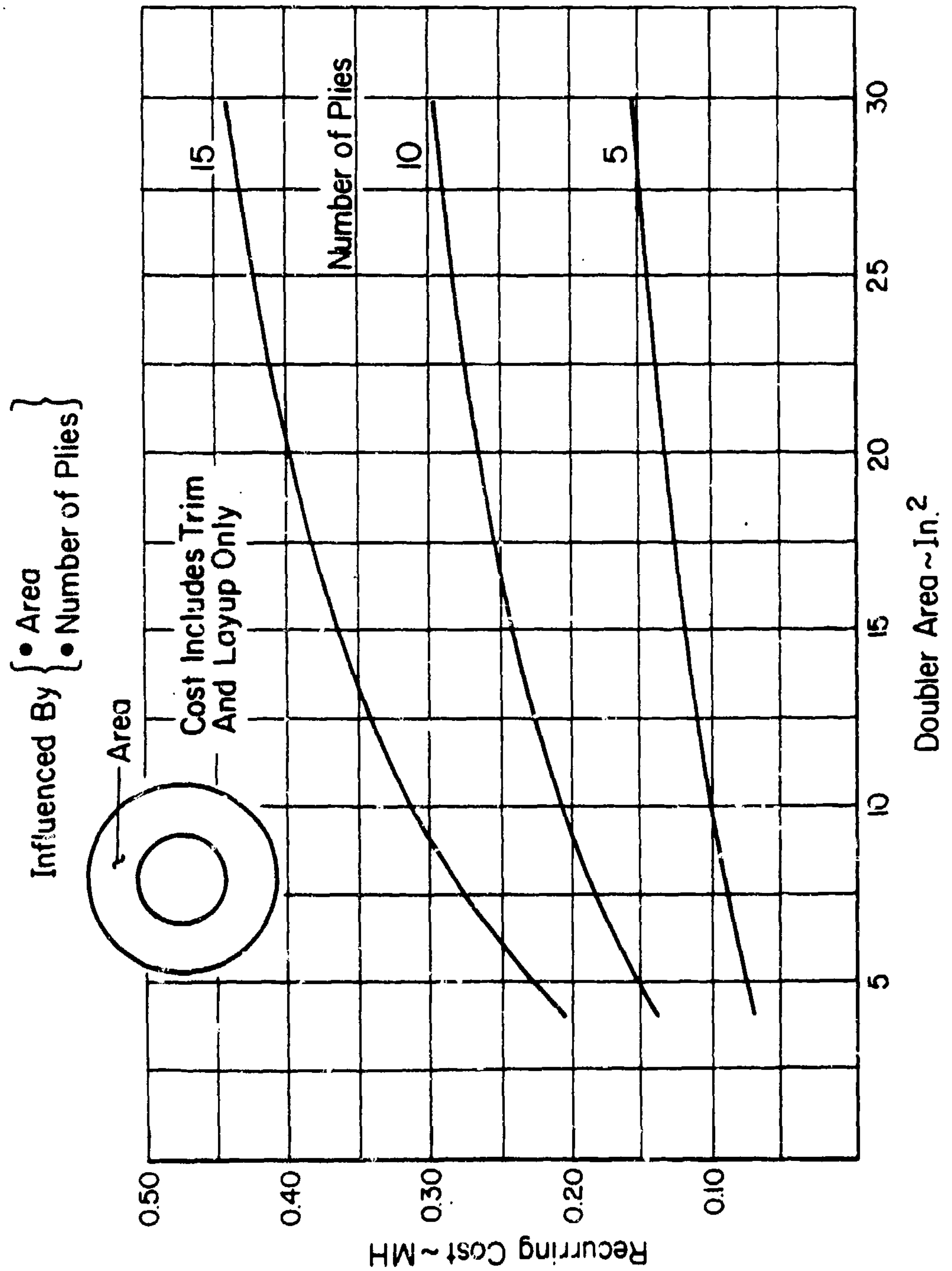
CUTOUT-HOLE RECURRING COST/DETAIL



SEE GROUND RULES FOR LIMITATIONS AND CONSIDERATIONS

DICE-G/E-2

HOLE REINFORCING DOUBLER FOR COCURING: RECURRING COST/DETAIL

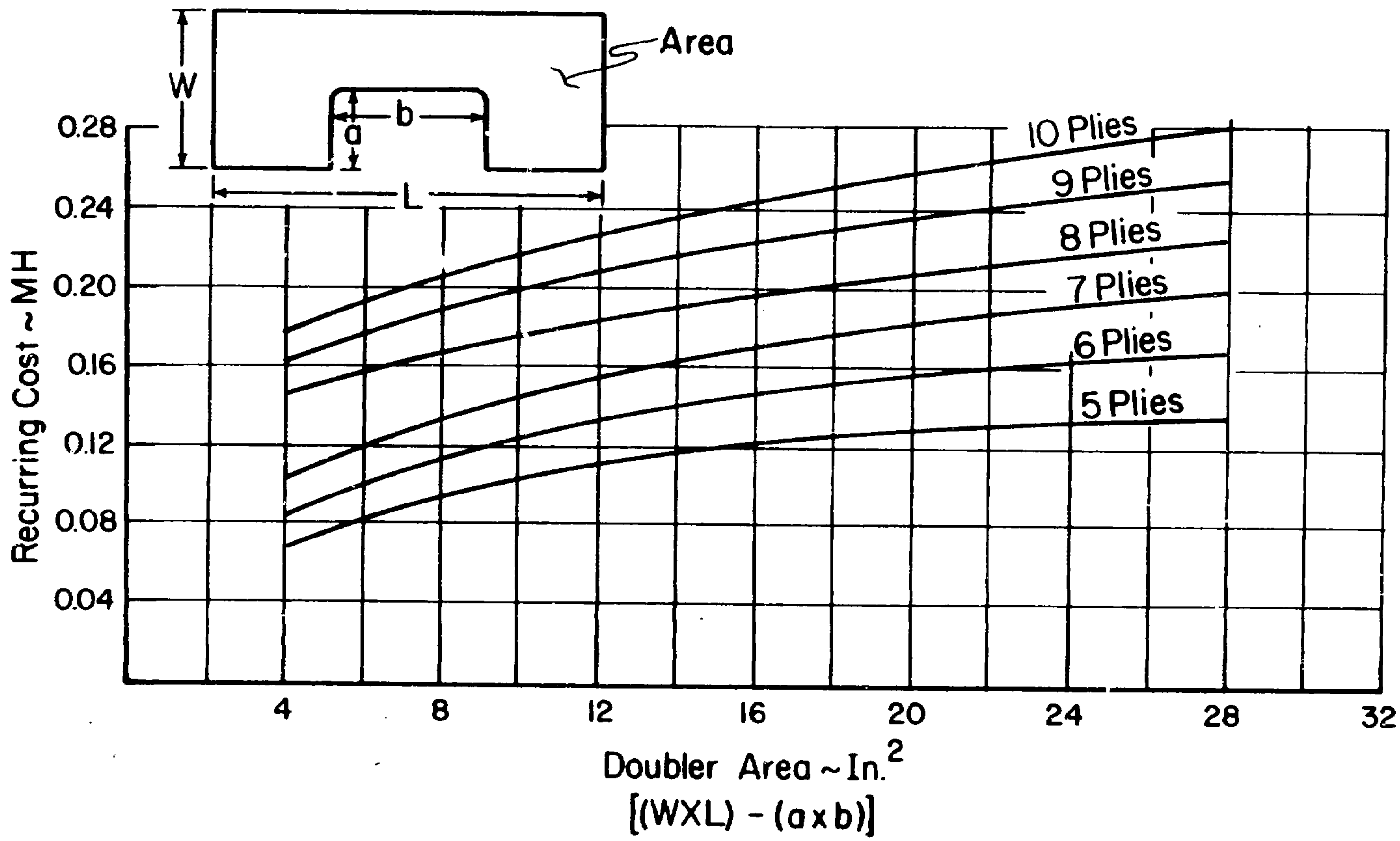


SEE GROUND RULES FOR LIMITATIONS AND CONSIDERATIONS

DICE-G/E-3

CUTOUT REINFORCING DOUBLER FOR COCURING: RECURRING COST/DETAIL

Influenced By {• Area, • Number of Plies}

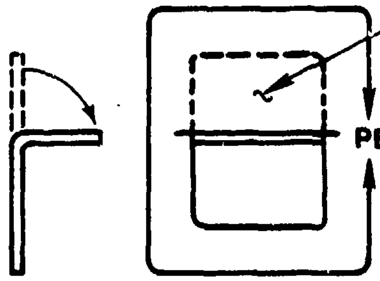


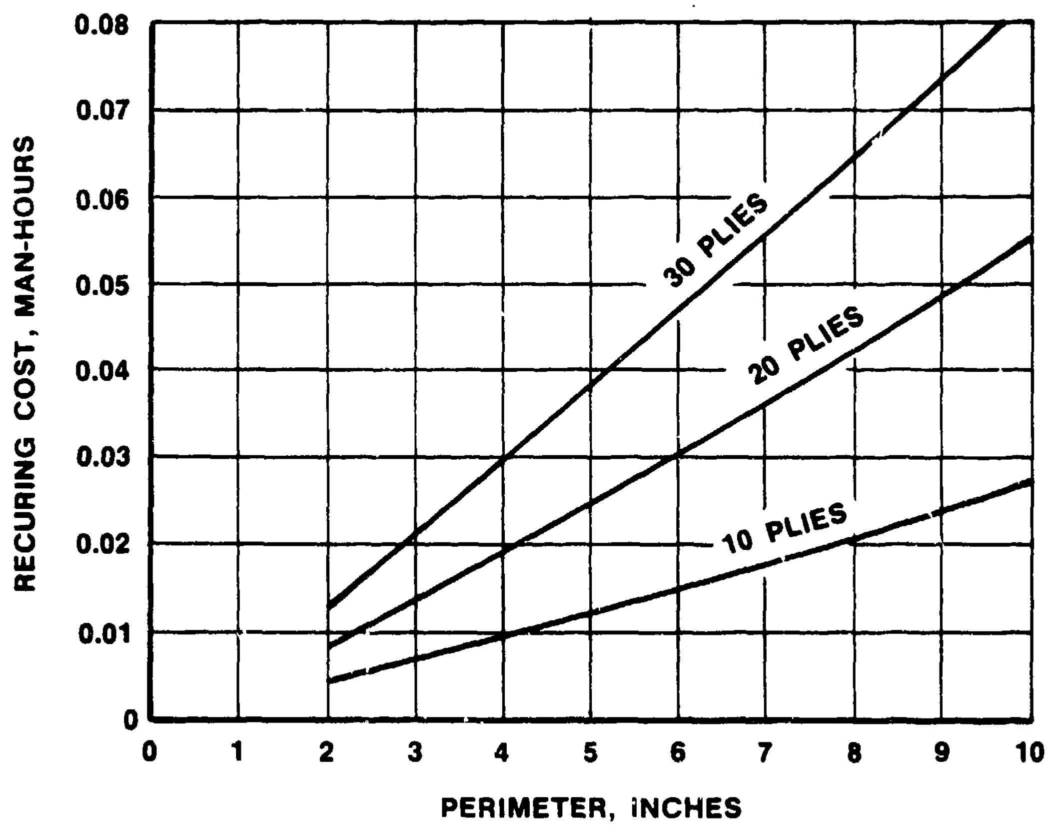
SEE GROUND RULES FOR LIMITATIONS AND CONSIDERATIONS

DICE-G/E-4

CLIP FOR COCURING RECURRING COST/PART

INFLUENCED BY { • PERIMETER • NUMBER OF PLIES }





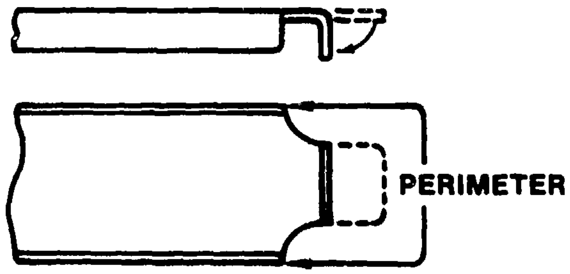
SEE GROUND RULES FOR LIMITATIONS AND CONSIDERATIONS

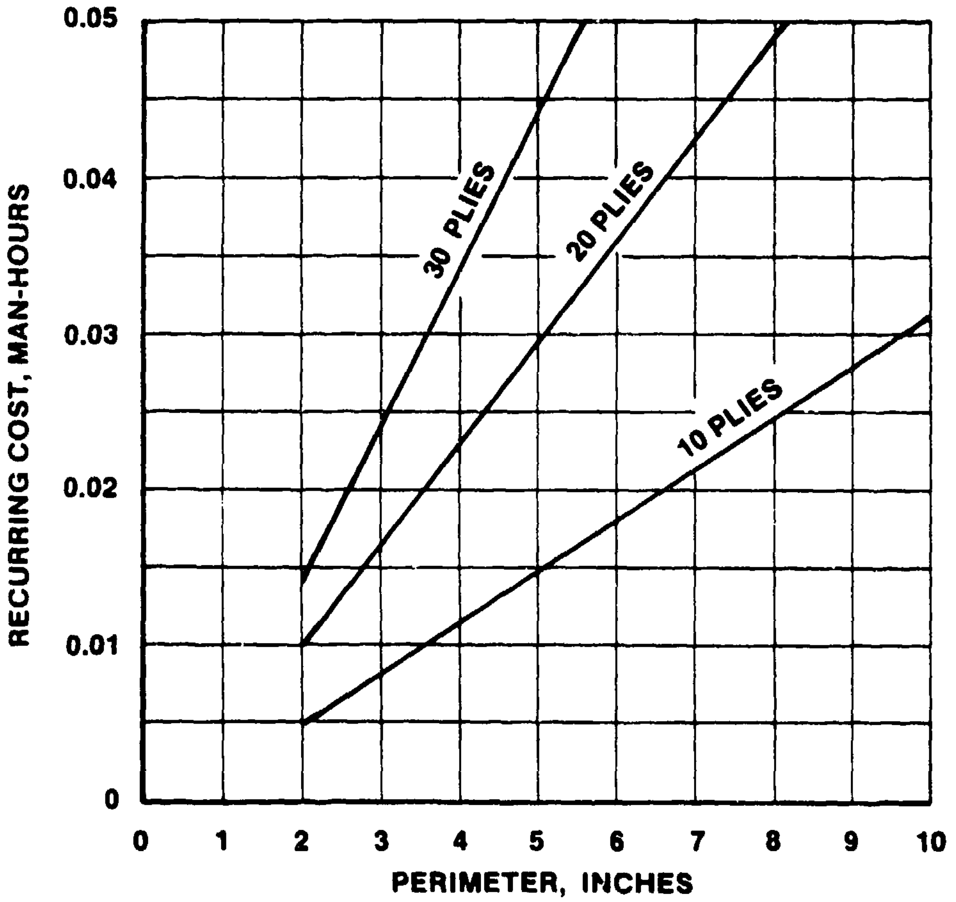
DICE-G/E-5

INTEGRAL TAB
RECURRING COST/DETAIL

INFLUENCED BY {
- PERIMETER
- NUMBER OF PLIES }

COST INCLUDES TRIM ONLY





SEE GROUND RULES FOR LIMITATIONS AND CONSIDERATIONS

DICE-G/E-6

4.3.5 Ground Rules for Advanced Composites Section

The following General and Detailed Ground Rules for the Advanced Composites Section were developed to establish the scope of the data required and to establish guidance to MC/DG application. Ground rules are necessary and important as they promote understanding, ensure consistency, uniformity, and accuracy in generating and integrating data into the formats.

4.3.5.1 General Ground Rules

The general ground rules were categorized under the following major groupings:

(a) Advanced Composite Discrete Parts
(b) Composite Material Types
(c) Manufacturing Technology
(d) Facilities
(e) Data Generation - Recurring Costs
(f) Data Generation - Nonrecurring Costs
(g) Support Function Modifiers.

The Advanced Composites Fabrication Guide (ACFG) glossary was used as a basis for terminology. The Advanced Composites Design Guide (ACDG), Advanced Composites Cost Estimating Manual (ACCEM), and the ACFG were utilized in the development of the MC/DG section, "Advanced Composites Fabrication".

(a) Advanced Composite Discrete Parts

(1) The selected base parts were representative of common structural shapes that were required in both small and large aircraft. They were selected such that a base part formed the foundation to which a designer could modify the part as required to achieve the desired structural configuration. Some of these structural shapes were applicable to the Phase III trade study.

(2) The selected discrete parts were defined and dimensioned to adequately display the effect on part manufacturing cost of designer-influenced cost elements (DICE).

(3) Support function modifiers, e.g., quality assurance, manufacturing, etc., were excluded, but could be treated by the MC/DG user at his discretion.

(b) Composite Material Types

(1) Composite materials were selected from those commonly used in the aerospace industry. This enabled a uniform data base to be established and enabled wide application of the manufacturing cost formats developed. The materials processing used was in accordance with the technical recommendations of the material suppliers, e.g., cure cycle and bleeder-ply ratios, except as noted in the detailed ground rules. The ACFG was utilized whenever applicable. Typical candidate material systems are:

- AS/3501-6
- 5208/T300
- 934/T300.

(2) As the cost of composite materials is constantly being reduced with increased usage, raw material costs were not included in the MC/DG formats. However, as raw material costs for composites have a large impact on the cost-effectiveness of these structures, current and projected prices must be included by the MC/DG user company.

(3) Material cost of nonrecurring tooling was not included.

(4) Honeycomb sandwich structures were not considered in this phase of the program.

(c) Manufacturing Technologies

(1) Only conventional manufacturing technologies, such as covered in the ACFG, were considered. No emerging manufacturing methods, such as robotics, were considered in Phase II(b).

(2) A production environment, in contrast to a prototype, was assumed for the advanced composite parts. Two hundred units were considered.

(3) To generate an effective data base for each selected part, a factory operational sequence for the selected manufacturing method and processes was established. This standardized sequence was used by each assigned team member to determine the base part cost using the ACCEM, wherever possible.

(4) Unidirectional strip plies were to be internal.

(d) Facilities

(1) For Phase II(b), only standard manufacturing facilities, currently available (1978-1979) to the airframe industry, were considered. However, it was recognized that if composites are to be more widely competitive with aluminum structures, automated equipment is necessary and development/implementation should be pursued by the industry on an expedited basis.

(e) Data Generation - Recurring Costs

(1) Recurring man-hour data were generated for the complete process of parts fabrication to include all hands-on-factory direct operations from conversion of the raw material to a finished part.

(2) The base-part cost was generated for each part type. The base-part cost represented the sum of all standard hours associated with each part as specified in these ground rules.

(3) Designer-influenced cost elements (DICE), requiring added operations, were treated as separate cost elements and not included in the base-part cost.

(4) In addition to the base-part cost data, costs associated with design complexities and the resulting cost drivers were identified.

(5) Cost data were represented in man-hours.

(6) Recurring tooling costs (tool maintenance, planning, etc.) are not included.

(7) The data submitted to BCL were the base-part cost and the costs of designer-influenced cost elements (DICE) provided separately.

(8) In developing cost data for parts, individual team company learning curves were used. Unit part costs were evaluated at unit 200.

(9) The part cost, as derived by each airframe company, was normalized by BCL to reflect an industry team average value for each part.

(10) For proprietary reasons, business-sensitive information employed at team member companies is not presented in the MC/DG.

(11) No data provided by any airframe company team member were disclosed to other team members, agencies, or to the public without the expressed approval of the team member.

(12) A pilot data collection run was accomplished and coordinated with the team members and BCL prior to completing the data generation task.

(13) Recurring costs included pattern trim, layup, debulking, cure, and trim of composite parts, unless otherwise specified.

(f) Data Generation - Nonrecurring Costs

(1) Tool fabrication costs were generated for each part type and assembly. The cost of tool design or support of tool fabrication and development of shop work orders (methods sheets) was not included.

(2) The costs of production contract tooling associated directly with the detailed fabrication of the parts and assemblies were the only tooling costs to be included.

(3) Nonrecurring costs generated by the team member companies were normalized by BCL for presentation in the MC/DG.

(4) Soft tools, such as rubber bags, bladders, and mandrels, were limited to 50 curing cycles. For 200 parts, the soft tool man-hours were factored by 4.

(g) Support Function Modifiers

(1) Additional effort other than factory labor, such as quality control and assurance and manufacturing engineering, was excluded from the part cost data supplied to BCL. These modifiers may be included later by the MC/DG users at airframe companies.

(2) Quality control (QC) of composite structures was a cost driver and should be considered separately by each airframe company using the MC/DG. This was because of the wide variation in individual company QC methods and methods of accounting.

4.3.5.2 Detailed Ground Rules

Detailed ground rules were prepared by the team to define the part shapes and manufacturing processes for which cost data were prepared and to provide for the uniformity in the costing methodology between companies. The parts and methods defined by these detailed ground rules were chosen to provide a common ground for cost data development, but the use of the MC/DG was not restricted to these exact part definitions.

The detailed ground rules were categorized under the following major groupings:

(a) Material

(b) Base Part Drawings and Sketches Used to Develop Cost Data for Formats

(c) Tolerances

(d) Estimating Method.

(a) Material

(1) The material system to be used was AS/3501-6 with a resin content of 34 percent ± 3 percent.

(2) 12-inch-wide unidirectional tape was used on all parts.

(3) Ply thickness, T, ranged from 0.005 inch to 0.007 inch.

(b) Sketches of Parts Used to Develop Cost Data

(1) See following two pages.

(c) Tolerances

(1) Tolerances for the base part configurations were considered to be: ± 0.03 inch on lineal dimensions and ± 0.00025 inch on thickness per ply.

(2) Tolerance for the cocured assembly was ± 0.06 inch on part location.

(3) A minimum of 0.25 inch was used on all interior radii.

(4) Fit-up maximum tolerances for cured details were 0.030-inch gap for "Mechanically Fastened Assembly" and 0.15 inch for "Bonding".

(d) Estimating Method

(1) The ACCEM was used as the base, with each team member company applying its own learning curves.

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